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Addressing Student Learning Barriers in Developing Nations with a Novel Hands-on Active Pedagogy and Miniaturized Industrial Process Equipment: The Case of Nigeria*

B. ABDUL,[1] B. J. VAN WIE,[1] J. T. BABAUTA,[1] P. B. GOLTER[1] and G. R. BROWN[2]
[1] School of Chemical Engineering and Bioengineering; and [2] Office of Assessment and Innovation, Washington State University, Pullman, WA 99164, USA. E-mail: bvanwie@che.wsu.edu

R. B. BAKO,[1] A. S. AHMED,[2] E. G. SHIDE,[2] F. O. ANAFI[3] and O. O. OLAOFE[2]
Departments of [1] Education, [2] Chemical, and [3] Mechanical Engineering, Ahmadu Bello University, Zaria, Nigeria.
E-mail: asahmed2007@yahoo.com

There is a global need to implement modern educational pedagogies. For developing nations, class size, utilities infrastructure, and a deeply entrenched lecture-based teaching paradigm are additional challenges. Our fundamental hypotheses are that classroom logistics in a transport class can be modified to use a novel pedagogy incorporating a Desktop Learning Module (DLM) for effective Hands-on Active Learning (HAL) in a developing nation and that enhanced learning will take place. HAL was compared to Lecture in a 127-student, 300-level Chemical Engineering (CHEN) class and assessed through multiple-choice quizzes and survey questions based on the Seven Principles for Good Practice. Follow-up faculty interviews were conducted to explore additional impact related to the introduction of HAL. For side-by-side comparison of the two pedagogies the class was split into two groups. These studies revealed there was significant but equal improvement in conceptual understanding for both the HAL (n = 59) and Lecture (n = 68) groups. However, surveys reveal HAL is in better alignment with Principles for Good Practice in undergraduate education. Faculty interviews add supportive evidence that students who experience the new pedagogy do better than those who do not. There is also an apparent spread effect suggesting that the introduction of cooperative learning strategies influenced faculty teaching and student learning behaviors. Also, the DLM device has features that encourage its adoption such as fast response, portability, and suitability for interfacing with a student group. The introduction of HAL pedagogy has important implications and holds strong promise in challenged learning environments as found in Nigeria. The DLM is found to be well suited for this environment.

Keywords: educational pedagogies; hands-on active learning; global; challenged environment; principles for good practice

1. Introduction

Enhancements of educational delivery using active and hands-on learning have been reported in numerous science and engineering education articles [1–5]. These articles posit that visual and tactile learning experiences have distinct advantages over a merely aural one [6–7]. This is particularly important in engineering because of the applied nature of the field. Kolb's experiential model [8–9], recognized as one of the suitable pedagogical models for engineering education [2], postulates active experimentation (or hands-on experience) as one of the four complementary stages of learning construction. This aspect of active experimentation has been mostly relegated to separate laboratory classes in engineering education with some attendant disadvantages such as student lack of autonomy in the learning process and less time for focused interactive discussion on specific concepts. Another incentive for studies in hands-on active engagement is that it has been identified as a precursor to persistence of students in an engineering major as well as playing a role in student migration from other majors [10–11].

Hands-on active learning has been implemented in a variety of ways including virtual laboratories [12–13], remote laboratories [14–15], seminar-type demonstrations [16], full-scale laboratory activities [2, 17] and in-class activities with full student involvement [18], each with its associated pros and cons. In-class, learning activities are thought to be unique because they facilitate simultaneous learning of engineering concepts and skills [18–19] instead of serial learning as would occur when lecture and laboratory are separated [2, 4, 20–21]. However, some challenges in implementing in-class active hands-on learning have been identified [18] and are more pronounced in developing countries such as those on the African continent. These challenges include [22] very large student numbers where, even for upper division courses, there can be as many as

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100–500 students all in an overcrowded room with insufficient seating, curricula limitations, time constraints, severe budget constraints, utilities that are unreliable, and use of dysfunctional pedagogies such as straight dictation. In addition to these challenges, lecturers have minimal preparation time because of the paucity of staff at the Ph.D. level, which is a fallout of African universities' expansion without the commensurate training of high-level staff [23]. These challenges must be considered when creating innovative solutions; obviously, if they can be circumvented then the benefits of in-class experiential learning such as enhanced interaction and retention can be realized.

The drive for international collaboration in the reform of engineering education [24] and the search for global competency in engineering [25] necessitate international cooperation in engineering education research. Because many developing nations have the advantages of abundant material and human resources [26–27], as is the case with Nigeria where the present study is taking place, they may be uniquely positioned to benefit from such collaboration with advanced countries for human capacity building so they can become globally relevant. The present paper summarizes an attempt to address student learning barriers in the Chemical Engineering program at Ahmadu Bello University in Zaria Nigeria where, during a Fulbright Exchange by co-author Van Wie, we used miniaturized industrial process equipment otherwise called Desktop Learning Modules (DLMs) to reinforce a new pedagogy based on Kolb's model [8] and the Seven Principles for Good Practice (7 PGPs) in Undergraduate Education [28]. The class of interest, CHEN 302, otherwise titled "Physical Transport Phenomena II: Heat Transport" is traditionally a sequel to CHEN 301 or "Physical Transport Phenomena I: Momentum Transport" and is traditionally taken in the third year of a five-year program. We assess the impact of using DLMs with the new pedagogy to assist in teaching heat transport phenomena principles of relevance to the education of chemical and mechanical engineers in light of very large class sizes, reduced availability of utilities, and unfamiliarity of students and lecturers with new learning styles. Furthermore, we assess the impact on conceptual understanding compared to traditional lectures, and use a survey instrument with construct validity [29] to discern how a hands-on active learning (HAL) approach influences student education. We suggest how success of the project in a Nigerian case study is creating opportunities for other regional institutions and other developing countries, and we look at course grades and GPAs, and analyze faculty interviews to do an assessment on the overall impact the HAL introduction has had on the students and the chemical engineering program.

2. Materials and methods

2.1 Equipment description

The DLMs (Figure 1(a)) are mobile and were designed at Washington State University (WSU) by a team composed of co-authors Golter, Van Wie, and WSU College of Engineering & Architecture Machine Shop personnel and an undergraduate student; the system design was reported in an earlier manuscript [30]. They do not require external hookups and have only a 14.8 inch x 12 inch footprint.

A sealed lead-acid battery powers a pair of small pumps as well as the pressure transducers, thermocouples, and read-out electronics. Two four-liter water tanks are built into the DLM footprint, to allow for hot and cold water use. Two DC motorized 8.3W centrifugal pumps (Rouchon Industries, Inc., Swiftech^{TM}, Signal Hill, CA) are situated underneath the DLM below the tanks while system flows are controlled in the 0–40 GPH range by adjustable needle valves on rotameters (King Instrument Company, Garden Grove, CA) located on the system on-off control panel. Type K thermocouples are built into the header where the modular cartridges snap in. Differential pressure transducers (Omega Engineering Inc., Stamford, CT) are also built into each module for the measurement of equipment pressure drop. Analog signals from the Type K thermocouple and Omega Engineering PX26-015DV pressure sensor are pre-amplified with a Burr Brown INA126 instrumentation amplifier (gain=148). Analog signals are made available from the DLM through a standard 9-pin DSUB. These signals are connected to a Measurement Computing USB-1608FS device. Version 5.1 Instical Software (Norton, MA) is used to transform the electric signals into temperature or pressure readouts according to the pre-calibrations. Stream data are then transferred to disk for data storage. Values of the variables are also presented to students through a cellphone display on the front panel of the DLM. The digital display returns a rounded value of the temperature reading, making the precision of each measurement ± 0.05°C.

A modular design for cartridges that snap into the DLM provides the flexibility to include several unit processes without having to increase the device footprint. The current cartridge options include three heat exchangers: a conventional shell and tube, double pipe and extended area radiator; and three fluid mechanics systems: orifice and Venturi meters, and a packed/fluidized bed. In many cases, for example the shell and tube heat exchanger

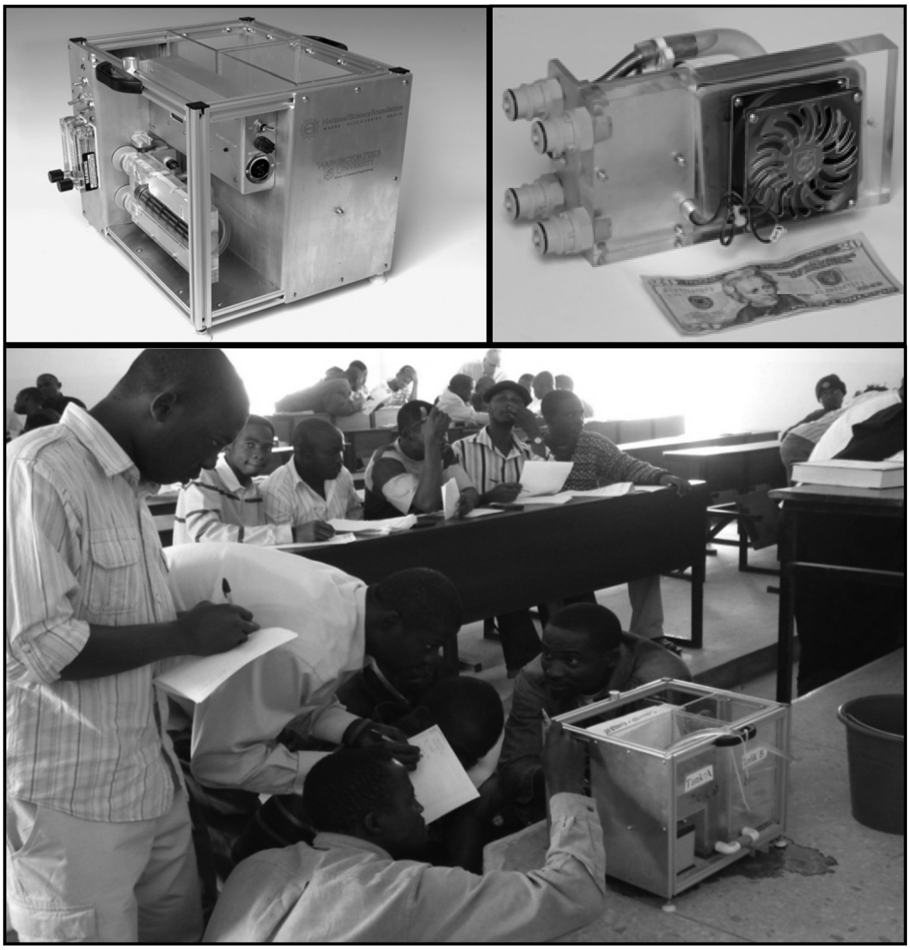

Fig. 1. (a) the DLM with a detachable shell and tube heat exchanger inserted; (b) the extended heat exchanger cartridge used in this study; and (c) a Nigerian HAL classroom with DLMs.

shown inserted in the DLM in Figure 1(a), the design is based on standard rules of thumb for heat exchanger design, i.e. window cut, baffle and tube spacing, etc., to construct a functional design. Figure 1(b) displays the cartridge design for a Swiftech$^{\text{TM}}$ extended area radiator system used in cooling computer CPUs (Rouchon Industries, Inc., Signal Hill CA) along with an 80 mm fan (Zalman Tech. Co., Korea)—the unit is the subject of the DLM study presented in this paper. Figure 1(c) shows the DLM/HAL classroom at ABU during Van Wie's Fulbright exchange with the ~1.2 foot cube DLM surrounded by a student team. Co-author Abdul interacts with one group front and center, while Van Wie is barely visible in the back interacting with a group that has returned to their seats while other groups appear in various places around the room assessing their data and comparing values they obtain from models they derive to represent the process being studied. To assess the DLM cartridge approach to steady state, online data collection is performed to record temperature data at 32 Hz which is then processed in Excel software using a moving 32-point average to report a data point every second.

2.2 Pedagogy implementation

The HAL pedagogy was introduced into CHEN 302, Physical Transport Phenomena II: Heat Transport within the Chemical Engineering Department at Ahmadu Bello University. Before the implementation of HAL, the students were briefed by the professor on the objectives and mechanics of the HAL. The topics to be covered in class during the HAL exercises were already contained in the departmental brochure which every student had and included the analysis of a double pipe, shell and tube, and extended area heat exchangers. They were also asked to endorse ABU administration approved forms consenting to the use of the data for publication purposes. The class objectives or learning outcomes for each cartridge implementation would read something like: "By the end of this set of activities the student should understand the concept of hydraulic radius and wetted perimeter amongst other related concepts and also be able to analyze and design an extended area heat exchanger"

The hands-on active learning employed in this class was particularly labor intensive and logistically involved. The professor handed out reading assignments and take-home quiz (the internet was erratic so e-mailing it to students would not be effective) to all the students on the topic to be covered two days before class. Typical of the take-home quiz questions, in particular for the extended area heat exchanger, are:

- Under what conditions is it necessary to use an extended area heat exchanger rather than another one we have studied?
- When designing a cooling fin what important factors will affect fin efficiency? Use equation 15.19 from McCabe [31] to explain how these factors affect fin efficiency.

When HAL was implemented, the method of convenient sampling was used to assign the 127 students into two fairly intellectually balanced groups A and B using their previous cumulative grade point average (GPA) as the convenient sorting criteria. Each group was further subdivided into subgroups of six students, with an equal mix of "strong", "average", and "weak" students. This was done to facilitate "balance" between groups with regard to benefits derived from intra-subgroup discussions during class and also for the purpose of group homework. We also noted that even though the groups were initially numerically symmetrical, some asymmetry was introduced during the implementation by some students not showing up during their assigned activities. However, all 127 students completed the class.

For HAL a guided-inquiry type worksheet covering major concepts and the experimental procedure was developed by the professor and handed out in class. This worksheet contains the professor's thought-provoking questions that are geared towards stimulating students' intellectual curiosity [32]. Four DLMs were set up on the platform in front of the class. Four student groups came up to the four DLMs simultaneously, interacted with the equipment (with the assistance of the instructors) over a period of about 10 minutes where they took measurements of water inlet and outlet temperatures as a function of flow rate, then went back to their seats where they continued with discussions on the worksheet. Meanwhile, the other groups kept busy discussing the conceptual and procedural questions on the worksheets as they awaited their turn with the equipment. The professor and the instructor(s) moved between the groups listening to the students, referring them to relevant text sections and tutoring as they circulated around. At certain points the professor stopped the group discussions to give 10–15-minute mini-lectures to correct some misconceptions, for example, on the concept of hydraulic radius, noted during discussions with students.

Paraphrased worksheet questions, e.g., for the extended area heat exchanger, appear below:

- Use an energy balance and your data to determine the mass flow rate of air;
- Use this mass flow rate and the geometry of your exchanger to determine the air Nusselt number;
- Determine the air side heat transfer coefficient;
- Determine the heat transfer rate using the model in your text and compare with what you obtained expermentally.

2.3 Comparison with Control Group

Late in the semester a controlled study was devised to compare HAL with straight lectures. The class was split roughly in half with 58 in lecture control Group A and 69 in HAL Group B. These groups were further subdivided into six-person teams (i.e. there were a maximum of six persons in any group). In this instance the HAL group studied an extended area heat exchanger, not seen in class previously, and in the lecture format the same material was covered. During the lecture the students filled in a worksheet identical to that used during the HAL experience (minus the physical data), but of course no hands-on equipment was present in the class for visualization of the miniaturized equipment. Exposure to the worksheet for the lecture students assured that both groups had a fair and equal chance of acquiring the same information. However, we view this as an "enhanced" lecture because there were some active discussions interspersed within the lecture format, and the worksheet itself may bias results as the students were given a pre-quiz that would alert them to stay focused on basic principles that would be covered in the lecture and worksheet. The lecture group later used the DLM (next day), but only took the same physical data as the other group and answered the related questions because they already had a lecture on the same topic. This was done to ensure that no student missed or felt they missed the benefits from the full pedagogy. This could also give stronger weight to positive comments about the two methods as some students could not only compare lecture versus hands-on when topics differed, but could also contrast the approaches for the same topic.

2.4 Assessment instruments

2.4.1 Multiple-Choice Concept Questions (MCQs)

The MCQ set used is a six-question test designed to assess students' understanding of concepts related to extended-area heat transfer. The test covered basic theory as well as derived equations of performance parameters. The multiple-choice method was adopted because it allows assessment of factual and evaluative understanding of the subject. It also provides comparison and evaluation of related ideas, concepts, or theories and allows ease of administration to a large number of students. The response choices to each test question were comprised of a key (correct answer) and the distracters designed to capture common student misconceptions of the subject. These common misconceptions have been identified by the designers over the course of their careers as faculty. The same basic test was given before and after the learning experience. However, measures were taken to ensure that student scores were kept from being influenced by factors other than ability, such as discussion within a group about which particular lettered answer was correct for a given question. To achieve this, two sets of questions were prepared and administered. One set differed from the other by a rearrangement of the sequence of questions and response choices for each question. We acknowledge the existence of a widely acclaimed and peer reviewed thermal and transport sciences concept inventory [33] which we note is generic and have found useful in our other related studies on course implementation [34–35]. However, because the questions in this validated inventory were not aligned with the DLM hardware and associated activities, we felt compelled to create an appropriate concept question list following some of the rules postulated by Zhao [36] such as the options should be equally likely to a lay person and the number of options should be at least four. The questions were reviewed by a panel of five lecturers with between 3–27 years of teaching experience and were found to be an adequate test of what was covered in this particular topic. The results of these two experiments were then collated and analyzed to assess uniformity of performance on the pre-test between the HAL and Lecture groups, and relative amount of improvement. Figure 2 contains a sample concept question used in our study.

2.4.2 Flashlight survey

The shortcoming of most exam types of assessment is that they help faculty identify only what students know and what they don't know. That information is valuable for both formative and summative assessments and for determining the efficacy of an innovation such as the HAL project. However, even concept-based exams do not reveal how students are learning the material. In addition, exams do not easily provide insights that can help improve student learning. A survey was developed to assess HAL with excerpts from the Flashlight Evaluation Handbook [29] and was designed to address the student learning strategy benefit or deficit and receptivity compared to the traditional lecture format in ways that might inform the implementation of the bundled innovation.

Specifically, the survey is based on Chickering and Gamson's [28] "7 PGPs," principles well vetted in educational research and broadly recognized for their construct validity, practicality, and their subsequent utility for improving teaching and learning practice.

A total of 25 questions were selected from a list of those typically used to assess the Seven Principles and framed in five-point Likert scale [37–38] to address issues such as how much the HAL method enhances team work, student grasp of concepts, and physical visualization of industrial processes. Examples of question wording are:

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

The *hydraulic diameter* for the air duct is the:

a) Ratio of fluid volume to total surface area, $\frac{H\cdot 2L_{fin}}{2(H+2L_{fin})}\cdot\frac{W_{fin}}{W_{fin}}$

b) Root mean side length, $\sqrt{H\cdot 2L_{fin}}$

c) Effective diameter for a pipe with the same cross sectional area, $\sqrt{\frac{4(H\cdot 2L_{fin})}{\pi}}$

d) Ratio of circumference to cross sectional area, $\frac{2(H+2L_{fin})}{H\cdot 2L_{fin}}$

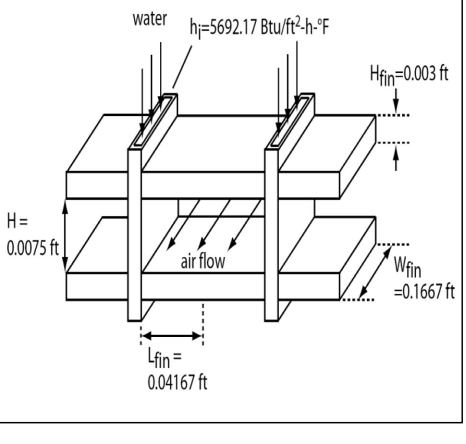

Fig. 2. Options and diagram for one of the multiple choice questions used in the study.

  - Hands on activities helped me understand the course concepts;
  - I was encouraged to answer my own questions.
- And compared to other courses to what extent do you
  - spend more time on tasks for this class?
  - Discuss topics of the course outside of class;

For purposes of analysis in this paper the seven principles are assigned numbers:

(1) faculty-student contact,
(2) student-student contact,
(3) active learning,
(4) prompt feedback,
(5) time on task,
(6) faculty's high expectations,
(7) recognition of students' diverse approaches to learning.

A separate section was provided for written responses with the heading "Other Comments" and screened for statements which would buttress the general findings from the collective trends observed in the Likert responses. Clearly the survey not only embodies the research into how people learn, but represents the core values underpinning the HAL pedagogy.

2.4.3 Student grades

While there are many factors that can impact classroom performance, one of the co-authors (Olaofe), who was the ABU Chemical Engineering Exam Officer who recorded all the grades for the Department, noticed a remarkable improvement in the performance of the students who were exposed to Van Wie's implementation of the group learning pedagogy. Furthermore, he noticed a corresponding change in student behavior, i.e. many more group meetings outside the classroom. Therefore, to further investigate the efficacy of the new pedagogy, student grades were compared for the present course, CHEN 302, with a previous lecture-only course, CHEN 301, along with GPAs before and after the course. For this we compared the present test set of students (n = 127) to a control set (n = 39) which did not experience the new pedagogy in any way. Paired t-tests were done on the overall student grades before and after the course of study and the first and second semester GPAs to check for any significant improvement from the repeated treatment within each group. To further check for significance of gains between the two groups, a classical two-sample homoscedastic (equal statistical variances, usually for repeated treatments where each treatment has an equal number of samples) t-test was done on the groups. The t-test helps to determine if the average represents the same population or not. Finally, an effect size evaluation was done to gauge the practical significance of the results. The assumptions of data normality and homoscedasticity were checked before applications of these classical tests of significance [39].

2.4.4 Faculty interviews

Six (6) ABU faculty members were interviewed by telephone to gauge their perceptions of how the new pedagogy had affected teaching and learning. Three of them were involved in teaching or grading CHEN 301 and CHEN 302 and the other three were ABU Chemical Engineering Department faculty who were familiar with what we were doing and who, by virtue of their departmental responsibilities, have a good perception of student behaviors and performance. They were asked to consider changes in student-student interaction, and if observing the new pedagogy had influenced their own classroom teaching. We were especially looking for information that would corroborate the findings in the flashlight survey, and especially what was observed in grade improvements as so many factors could explain the phenomena.

3. Results and discussion

3.1 Equipment performance

There are important technical questions to answer about DLM performance to determine its suitability in addressing learning barriers particularly in developing nations:

- Can a given heat exchange cartridge, in our case the extended area heat exchanger, produce measurable temperature changes when cooling ~50ºC (122ºF) water with ambient air in equatorial countries, where there is no air conditioning in the classrooms, and inside temperatures can be as high as 30ºC (86ºF)?
- Will the system reach a quasi-steady state operation quick enough so that a large number of student groups can rotate through a DLM station and have a hands-on learning opportunity? This is important given the typical 100–300 student class sizes, even in courses within a major, and the limited number of DLMs that can be used in a single classroom because of budget and space limitations;
- Given the DLM hot water reservoir volume of 4 L how long can we sustain a temperature that's higher than ambient before reservoir contents need to be replaced? This is especially important since electrical power is erratic and we have to consider heating the backup supply of hot water perhaps with the use of a gasoline-powered generator as a power source;

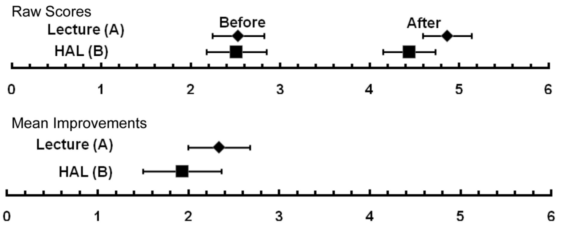

Fig. 3. Analysis of variance (ANOVA) plot for the Lecture (A) vs. HAL (B) study on the extended area heat exchanger material. The average raw scores and average difference for both groups in the pre and post tests show mean improvements with substantial overlap in 95% confidence intervals.

- Are there anomalies in the system that make for good engineering learning experience?

The following is a summary of pertinent findings on the DLM-radiator cartridge performance which is also characteristic of what is observed for the double pipe and shell and tube heat exchangers.

Quasi steady state is reached after 6, 16, and 24 seconds for water flows of 20, 10, and 5 GPH. As expected these are all within the residence time for the flow through the radiator volume, but it also says there is not a large heat sink in the system that prolongs the approach to steady state.

Changing the flow rate gives a new quasi steady state in a very short time (~ 15 sec). Because of rapidity of approach to steady state our experience showed a six-person student team could become acquainted with a DLM and acquire a set of data within 5–10 min. This allowed all 127 students, in 21 teams, to rotate through the DLM stations in our two-hour class period. Starting at 63°C, it takes about one hour for the temperature to drop to a point that is within 1°C of ambient temperature where it is necessary to either recharge the tank with hot water or reheat the energy-depleted water with an immersion heater.

3.2 Student Performance

3.2.1 Concept Tests Results.

In our HAL vs. Lecture study the ANOVA plot below shows the average scores on a six-question test; mean improvements appears in Fig. 3 for the Lecture (A) and HAL (B) groups.

Four ANOVA Tests were applied to the data to check for significance as summarized in Table 1.

The Confidence Interval plot visually displays the results of the tests where a clear break between two points indicates a significant difference, and an overlap between two points indicates no significant difference for the tested populations. Table 1 provides the statistical results of the four tests.

The four ANOVA tests provide the basis for a quantitative understanding of HAL in teaching students. There is no significant difference in the pre-lecture/HAL Concept tests performance between Groups A (Lecture) and B (HAL) as expected. This suggests that the students in both groups had about the same preconceptions. From the ANOVA and Confidence Interval plot we can see a clear improvement for both groups. For Group A and Group B, improvements from an original mean score of 2.5 to final mean score of 4.9 and 2.5 to 4.5, respectively, are seen out of a total score of 6, respectively. Finally, a fourth ANOVA on the mean improvements between Group A and B shows there is no significant difference between the performances on the CQ. Thus we can say that the HAL and lecture groups had about the same grasp of the extended area heat exchange concepts. This strongly counters the objection raised by faculty attending at every institution and every seminar given by co-author Van Wie on active learning, that students will not learn the material well when learning from each other in a discussion-oriented fashion as opposed to just listening to a lecturer who has significant expertise in the field. It is particularly important to point this out to international faculty where the use of lecture is a strongly entrenched tradition.

However, the statistically insignificant improvement of the HAL group is worthy of comment because it was expected that the HAL group would significantly outperform the lecture group as noted by Prince's review [40] which shows that active learning works but there is a need for careful metrics to gauge the degree to which it does. Prince also pointed out that assessment of active learning is difficult because it usually affects more than one learning outcome and therefore should be assessed using mixed methods, a notion also supported by

Table 1. Summary of ANOVA results.

ANOVA Test	***F* statistic**	**p-value**	**$F_{0.95}$[1]**
Mean scores before class	0.01	0.924	3.92
Group A improvement	139	0.000	3.91
Group B improvement	75.5	0.000	3.92
Mean improvements	2.22	0.139	3.92

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[1] Tabulated values taken from Perry's *Chemical Engineer's Handbook,* 1983.

Adams *et al.* [41]. He also suggests that interpretation of the results should be carefully done to avoid misinterpretation and over-interpretation in view of the learning objectives. Based on some of these considerations, the anomaly (although statistically insignificant) in the HAL-Lecture results could be attributed to a misalignment of the assessment tool (the MCQs) with the hands-on activity [34] or some other inadequacy in the design and interpretation of the MCQ [36].

We suggest also that since the lecture itself was active (the HAL and lecture groups differed mostly in the in-class DLM experiment) and the same concepts were discussed by both groups with the instructors leading in both cases, the same reading assignments, take home quiz, and worksheets (with an additional data table for the HAL group) were given to both groups during the class, the five-minute MCQs may have been inadequate for testing any intergroup difference and the close similarity in treatment of both groups could mask any differences. Also, five minutes is not enough time to test a difference in analytical/problem solving skills between the two groups. We further posit the possibility that there exists an inadequacy in the design and interpretation of the MCQ especially regarding the number of questions which is below the minimum of eight recommended by Zhao to mitigate the effect of guesswork [36]. Golter *et al.* [35] have also highlighted the inadequacies of traditional control studies in education research and proposed a more rigorous experimental model with less emphasis on quantitative studies. This model is centered on a project-based approach with design discussions reviewed for critical reasoning by students and faculty within the experimental site institution and industrial representatives outside the institution. Of course, delivering the course content is not the only objective in teaching. In fact, the Flashlight Survey will show that the HAL method helps the students to develop some useful skills and has better receptivity than the lecture. In future, we plan to report on project-driven learning with the DLMs as support equipment and use of a critical reasoning assessment instrument to measure various associated learning outcomes.

3.3 Flashlight Survey

There was an excellent survey response rate (116 of the 127 students (93.5%) who participated in the study turned in their surveys). While no student responded to every question, all of them responded to between 80 and 90% of the questions. While the seven PGPs were woven throughout the 25 questions and six categories, for purpose of analysis the response assessment was realigned with the Seven Principles. We note that some of the questions align with more than one principle, in which case we chose the principle with the closest alignment based on consensus agreement between four of the co-authors all with considerable experience in pedagogy assessment. Fig. 4 presents analyses of questions based on the PGPs. Only response averages are shown for each principle to avoid clutter. However, response results on specific questions are woven into the discussion in the form of percentages.

Figure 4a presents a result for faculty-student contact, PGP1. Regarding PGP1, 76% said they were likely (42% much more and 34% somewhat more) compared with other courses to discuss ideas and concepts with the instructor and only 8% said less likely. A striking 84% were more likely to ask for clarification (55% very likely, 29% likely), and counter to the culture of unquestioned respect for authority in Nigeria we found that 65% (28% much more and 37% somewhat more) felt more comfortable disagreeing with something the instructor said while 10% were less comfortable. Further insight into PGP1 was gained from student responses on whether they felt more isolated with the new DLM pedagogy. About 65% of the students responded they felt 'much less' (46%) or "somewhat less" (19%) isolated. This question served as a good control against students simply rushing to fill in the left-most dot, and generally more desirable responses, on the survey sheet because in this case the more desirable responses, of 'less' and 'much less' likely, were on the right-most side. The 'Other Comments' section contained strong statements in support of the argument that students are more motivated to learn in a setting which promotes student-faculty contact. For example, a student commented that the new DLM pedagogy "should be extended to other courses taught within the department as it encourages the lecturer-student relationship".

Regarding PGP2 (Fig. 4b), 90% of the students (56% much more and 34% somewhat more) said they were more likely to interact with other students. Only 4% were less likely to interact with other colleagues. Similar responses were given on questions about discussions inside and outside of the classroom (78% more likely, 14% less likely, and 8% same), and improved collaboration with peers (82% more likely, 9% less likely, and 9% same). The collective responses on questions related to PGP1 and PGP2 suggest that the students recognize that effective learning is collaborative and social not competitive and isolated and that this has been encouraged by the new pedagogy. Furthermore, in analogy with the various types of physical transport phenomena, we posit that the driving force for knowledge transfer from faculty to students is the considerable knowledge and experiential gap between them. However, a lack of deliberate and

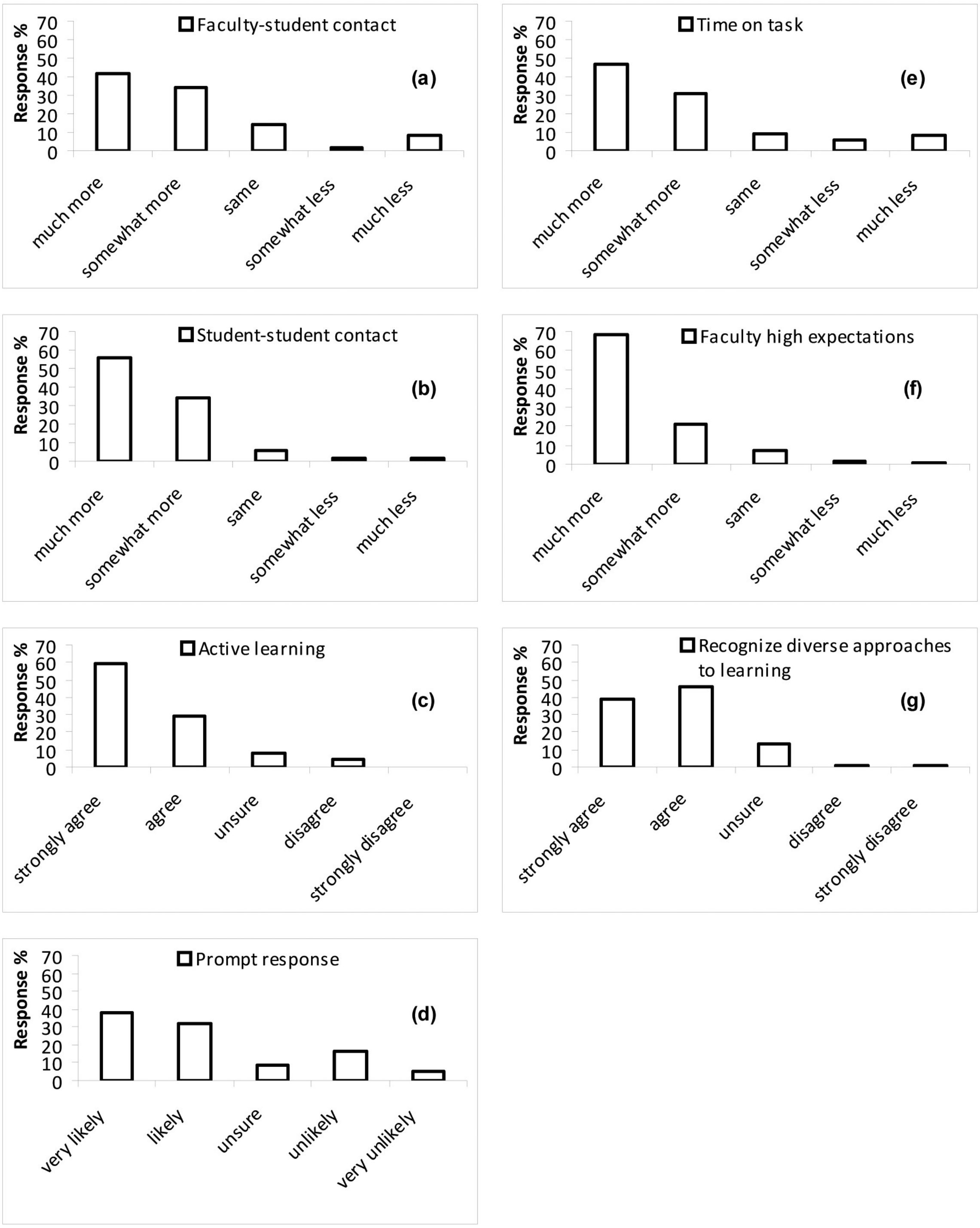


Fig. 4. Depiction of flashlight survey responses on indicators for the Seven Principles for Good Practice in Undergraduate Education [28].

engineered mutual contact and interaction can indeed retard this transport rate. We submit that the new pedagogy and the DLM have been recognized by students as considerably reducing this impedance.

In line with PGP3 and PGP4 Figures 4c & d focus on active learning and prompt feedback. An overwhelming 87% agreed (50% 'strongly agree' and 37% 'agree') that hands-on helped more than lecture. Only 6% disagreed (5% 'disagree' and 1% 'strongly disagree'). When asked if hands-on made them better able to visualize ideas, a significant 94% (67% 'strongly agree' and 27% 'agree') responded in the affirmative. This position was reinforced by a student who said: "All in all I enjoy the practical method of learning (better) than lecturing". Another student said, "I personally would like the hands-on learning to be employed in all chemical engineering courses. It really helps to visualize what I'm being taught and think myself; instead of being fed all the knowledge and forced to swallow" Yet another student remarked: "This method helps to visualize processes and gives a better understanding of concepts given in the textbooks". This statement appears to conflict with the Concept test results (Fig. 4) which indicate that there is no significant difference in conceptual gains between the HAL and lecture groups. It is noteworthy, however, that the Flashlight Survey was administered at the end of the semester after all the students had been exposed to hands-on learning and lecture at some point. Thus this position may reflect more on the superior sensory perception and retention offered by a combined aural, visual and tactile experience compared to just an aural one [18].

Because the HAL design had in-built hands-on activities (PGP3, active learning), students had little option but to work together in class as they were instructed to come forward to observe DLM processes group-by-group and they were asked to complete in-class worksheets as a group. Whenever it was noticed that several students were sitting by themselves, they were asked to join with their group while at the same time their group was encouraged to receive them. Nevertheless, the question remains whether the general nature of working together persisted outside class and whether it was carried over to work in other classes. To answer this we can look at the response results for two questions. First, on whether students were more likely as a result of the hands-on active experience to discuss topics outside of class we find 78% said they were 'very likely' (39%) or 'likely' (39%) to do so. Secondly, when asked if they were more likely to work on assignments with other students, we find 82% said they were 'very likely' (49%) or 'likely' (33%) to do so. Responses to other questions, such as whether HAL encouraged students to answer their own questions, realize connections between different areas, are more comfortable in discussions, or are pushed to think independently, show the same overwhelmingly positive skew.

Further evidence to support the assertion that the HAL experience was transformative would hopefully be found in looking at class performance and the impact the experience has had on other coursework—preliminary performance indicators will be discussed in the next section.

Concerning whether the in-class activities caused them to miss comments made during a discussion about ideas and concepts taught, there was a more uniform response across the scale with 20% checking 'very likely', 17% 'likely', 28% unsure, 25% 'unlikely', and 11% 'very unlikely'. Still we view this latter trend as positive considering that the students were much more inclined to ask for clarification which encourages feedback from the instructor (PGP4). Furthermore, literature shows that the scenario with the standard lecture is far worse as after the first 50 minutes of lecture retention, levels are only at about 20%, that is 80% of the material is effectively missed by students after this point [42]. Concerning whether they were likely to give suggestions or complaints, about 60% responded in the affirmative. This again is in line with PGP4 which encourages a two-way feedback that generally serves as a precursor to system improvements.

Figures 4e, f & g show some responses to questions that combine the last three principles. Regarding PGP5 (time on task), 88% (47% 'much more' and 31% 'somewhat more') were likely to spend more time to learn new material than before. This reflects good practice which posits that time and energy are necessary for learning. Only 14% said they were unlikely to spend more time on task. Regarding PGP6 (high expectations), 89% (68% 'much more' and 21% 'somewhat more') felt they were more prepared for the engineering field; 95% agree (65% 'strongly agree' and 30% 'agree') they are better able to grasp facts; 89% (63% 'strongly agree' and 26% 'agree') agree they gain a more thorough understanding of the ideas which coincides with the 84% (45% 'much more' and 36% 'more') that indicate they had to create their own understanding of the information to be learned. All these align with high expectations for students by faculty. Regarding PGP7 which recognizes diversity, 89% feel they are more likely (61% 'much more' and 28% 'somewhat more') to learn in new ways. Another 85% (39% strongly agree and 46% agree) agree they have a higher tendency to consider contrasting points of view because of the new pedagogy. This suggests that the students have a better appreciation of the diverse ways of viewing a problem and, through this, are learning more from their colleagues and are thus better prepared for teamwork.

When asked if they were satisfied with the introduction of hands-on group learning, survey results are positive with 95% responding they were either 'very satisfied' (51%) or 'satisfied' (44%) with the pedagogy. Only 3% indicated they were 'unsatisfied'. We note that one question leaves us with some uncertainty, however. When asked if the learning technique is overrated, 46% (20% 'strongly agree' and 26% 'agree') replied in the affirmative, 17% are 'unsure', 18% 'disagree' and 15% 'strongly disagree. Further evidence to support the fact that some students had concerns or would like modifications to the approach is suggested by a student who wrote

*"*A special class should be separately organize(d) to take care of the hands-on rather than using (the) normal lecture hour". This may be because students are yet to become totally comfortable with the new teaching method. Still the mixed responses to the "overrated" question are surprising given the overall satisfaction expressed. This leads us to wonder if the question was misunderstood and we plan to add a phrase in future surveys that says " . . . overrated and I would prefer the standard lecture or some other teaching approach". We will follow this immediately with a request like "If you agree that the technique is overrated, please state your reason why and offer suggestions on how to improve the approach." We also posit that this could be in line with the "high expectations" principle of good practice as the students could have grasped all that was offered in this introductory exposure and are therefore yearning for an enhanced experience. We aim to pursue this line of argument and to modify the pedagogy to accommodate more challenging concepts. Further inferences drawn from the other comments section of the survey are as follows: out of a random sample of 50 students, 15 suggested that this approach be extended to other courses, 13 were of the opinion that the HAL has helped them to be more appreciative of team work, 15 said it enhanced their grasp of key concepts and also helped them to relate theory and practice. Another four of the respondents were of the opinion that more time should be allotted to the HAL class, one person suggested that a special class outside normal classes should be created for it, and two respondents said they preferred the normal lecture format to the HAL.

In addition to the preceding analyses, the students were observed to use some terminologies in their everyday conversation, the context of which exhibited their grasp of the fundamental ideas of the subject. Below is a sample of the comments (in "pidgin", a common local language in Nigeria): *"Prof transfer coefficient high today o..!"* [the student is excited that the Prof's "knowledge transfer coefficient" is high]. *"Old boy I don reach steady state for today, I dey go sleep . . ."* [the student has had all the studying he can handle for the day and compares his state to the concept of steady state].

Overall, the reception to the DLMs and hands-on active learning approach has been quite encouraging. As students are exposed more to this new method, the authors have no doubt they will continue to find it stimulating and useful in their learning.

3.4 Interviews with ABU faculty

Faculty interviews corroborate the survey results showing classroom organization, instructor interactions and experiences occurred with the implementation that strongly promoted the seven PGPs. In addition, they give credence to the enhanced scores in CHEN 302 over 301 and GPA improvements for the test group when compared to the control group as will be described in the next section. More importantly there's evidence the new pedagogy is having a transformative effect on the other faculty as a whole, and finally the interviews reveal some important concerns about the DLM system that should be addressed to improve on HAL efficacy.

Regarding the observation of evidence for the seven principles we highlight the following comments. One of the interviewees implies that the pedagogy gets the faculty more engaged with the students and comments, "(there are) strengths both for the teacher and the students", PGP1: faculty-student contact. One faculty said, "They have better teamwork skills"; another said, "I see students studying in groups." This lecturer "attributes it" to the new HAL approach; others said: "I noticed that students are very much at home in a group study environment and they learn so much from it . . . If you give a lecture some students will understand one part more than others . . . by the time they interact with each other they are now able to combine the knowledge into a whole", PGP2: student-student contact. "Prior to Dr. Van Wie, we are not used to the modules . . . It is commendable that now students in the department have this opportunity. It is really very good for them and I think they are really excited." Another said, "When I was a student I had problems translating what the teacher says into practical visualization . . . but now you are able to see pressure in very practical terms . . . It was very thrilling . . . I really enjoyed his approach" . . . "I saw students coming together trying to solve problems, trying to explain things to one another a couple of months after Professor Van Wie had started teaching them". Finally, another said "(to) visualize (is) better than imagination . . . I strongly believe this approach is the best", PGP3: active learning. Others infer that the implementation has heightened faculty expectations (PGP6) especially as it applies to group work, "I now see students working in groups in the classroom . . . in the departmental library . . ." or "Sometimes I'll be passing by at night and . . . discovered . . . students studying in groups." "(the) strength of group study is the tremendous speed with which things get done. When you have people from different backgrounds working together, they look at problems from different perspectives", PGP7: recognition of students' diverse approaches to learning.

It is well established that group activities, projects, and homework sessions lead to enhanced classroom performance [43], and retention [44], and can lead to a spread effect that stimulates enhanced performance in other classes [45]. When you see the definitive increase in overall student performance (cited below in the section on *"Impact of the new pedagogy . . ."* you must admit there can be many factors that could affect performance in any specific class and overall performance in the breadth of classes taken by a student in any semester. However, during the time of the HAL implementation there is strong commentary evidence from other ABU faculty of an immediate and transformative shift toward group activities. Hence, the positive Flashlight surveys and improved performance in CHEN 302 and overall GPA (see next section) for the test group is consistent with the literature reports. Supportive faculty comments include "I now see students working in groups in the classroom close to my office and in the departmental library . . ." "Sometimes I'll be passing by at night and I will think a lecture was going on but then I discovered it was just students studying in groups." "I saw students coming together trying to solve problems, trying to explain things to one another a couple of months after Professor Van Wie had started teaching them".

The following comments illustrate that the HAL implementation, though it only occurred in two classes over the course of Van Wie's Fulbright exchange, was transformative for the Chemical Engineering faculty at ABU and that a philosophical shift has taken place, as emphasis on altered pedagogical approaches is becoming ingrained throughout the curriculum. "Lecturers are now giving more group work to students. I see more group work in the department but not necessarily on the DLMS" . . . "The approach has challenged faculty to go back and learn how to teach with DLMs." "Particularly the equipment he brought. I got attracted to them because I had already started seeing things in that way . . .When I was a student I had problems translating what the teacher says into practical visualization . . . but now you are able to see pressure in very practical terms . . . It was very thrilling . . . I really enjoyed his approach." "I used a variant of Prof. Van Wie's hands-on to teach Bernoulli equation using different bank note denominations to represent the different terms in the Bernoulli equation". When asked "Do you think you would use group work in your classes?" one lecturer responded with "Definitely I will. I may even say I have started it with what Dr. Van Wie introduced . . ." . . . "When students see things practically they are better able to view things and comprehend and follow and make contributions".

Regarding whether he used group work or study another responded with "Yes I do. . . . CHEN 301 . . . which I taught with two of my colleagues. We used the hands-on equipment to teach the students. We taught the students orally and also allowed them to have hands-on experience themselves."

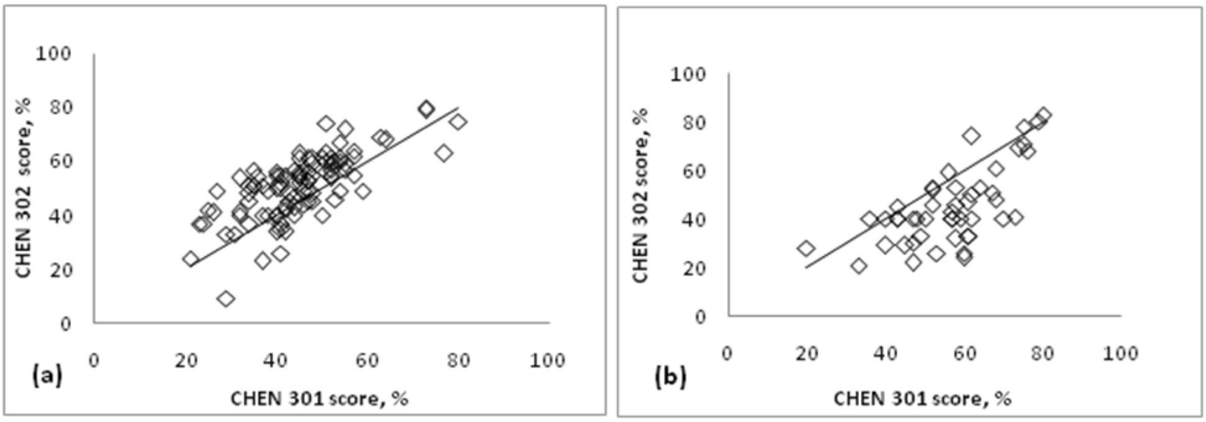
Faculty members also expressed healthy concerns about the alternative pedagogy, concerns which are likely to help them beware of the potential pitfalls and implementation barriers to active, group, and hands-on activities. For example, two of them pointed out the need for proper training and support materials. Specifically, a senior faculty who used the DLMs in his class complained that: ". . . most lecturers are not properly trained in the pedagogy, there were no facilities to repair them (the DLMs) and there was no operations manual . . ." While draft copies of the operations manual were subsequently made available, the interviewee brings up a good point that ample training and exposure to operations procedures is important. When done properly with a guided step-by-step DLM operating procedure we find students and lecturers have a learning curve of about 10 min after which use of DLMs in subsequent classes, even with use of alternate cartridges, does not require more than 1–2 min of further instruction. Also, since the time of implementation, training of technicians on trouble shooting the DLMs has been conducted. Also, a World Bank-sponsored collaborative research project between WSU and Ahmadu Bello University (ABU), Nigeria is in progress to develop and disseminate the DLMs, workbooks, and pedagogy to all major universities with chemical engineering programs in Nigeria. Another major issue identified is that of plagiarism. This can be exacerbated in the group setting especially in the large classrooms that typically exist in developing nations and where average students can take 20 credits or more. Van Wie himself notes that a student commented to him that if he gives too much homework it just encourages them to copy and when he first introduced the group work in the classroom found he spent considerable time one period collecting electrical engineering homework that was being copied by students for another class. He notes however, that had he not been circulating during the group time he would not have noticed and would not have been able to correct the problem. Others addressed the tendency that group work has in tempting plagiarism and offered other solutions to keep in mind when implementing a HAL approach. For example, one said: "There's less tendency for plagiarism when the group is well blended. Only unserious students indulge in plagiarism." Another proffered this solution: "To avoid plagiarism, we ask them to do presentations and ask them questions randomly and we can thus identify the slackers . . ."

3.5 Impact of the new pedagogy on overall student performance

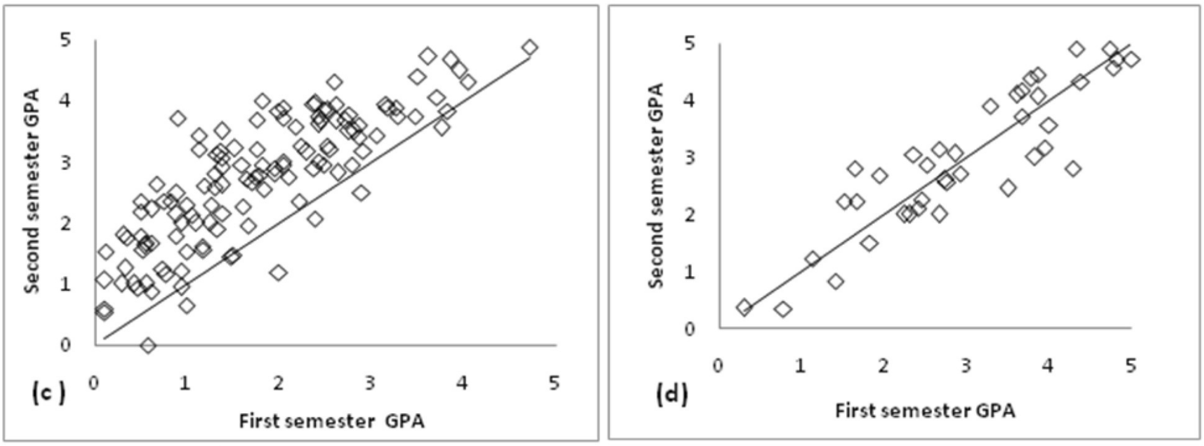
Because of the enthusiasm with which the DLM/HAL pedagogy was received, we expected students' performance would improve in the CHEN 302 class at hand over that of the prerequisite CHEN 301. Moreover, if the groups were truly effective we might expect a carryover effect where the mentality would persist in a way that group study, at least on homework and projects, would continue in other classes taken by the same students and that this might improve their average performance as evidenced in GPA. The presence of a transformative group mindset was confirmed through the faculty interviews (above) where they report they saw an increase in the number and frequency of student study groups after the introduction of the new pedagogy and that they were encouraged to include active and hands-on elements in their classes.

Figure 5a shows final class percentages for individual students in the study group in CHEN 302 where HAL was introduced to those having the prerequisite CHEN 301 which did not employ HAL. Final class percentages for a comparison group from the previous year when neither CHEN 302 nor 301 used HAL are shown in Figure 5b. A similar comparison for the GPAs in the second semester when the new pedagogy was introduced to the semester before for the study group is shown in Figure 5c; similar results for the same control group are shown in Fig 5d. It can be observed that for the majority of students in the test group, the final class scores for CHEN 302 and the second semester GPAs were generally higher than for the first semester when the new pedagogy had not been introduced. On the other hand, the control does not show similar improvement but rather we notice that only a few of the final class scores improved and the GPAs appear stagnant on average.

Table 2 is a summary of the statistical analysis that was done on the class scores and GPAs to check



CHEN 302 vs. CHEN 301 scores (a) HAL; (b) Control



Second vs. first semester GPAs: (c) HAL; (d) Control

Fig. 5. Scatter plots for course scores (a) experimental and (b) control; and GPA (c) experimental and (d) control.

Table 2. Summary of t-test results at 5% risk level

	Test Group Class Scores	Control Group Class Scores	Change in Scores; Test vs. Control	Test Group GPA	Control Group GPA	Change in GPA Test vs. Control
Hypothesized mean dif.	0	0	0	0	0	0
t statistic	6.59	6.84	10.0	16.3	0.043	8.22
t critical [one-tail]	1.66	1.68	1.66	1.66	1.69	1.65
t critical [two-tail]	1.99	2.01	1.98	1.98	2.02	1.98
Effect size	0.048	0.076	0.181	0.874	0.003	2.43
Statistically significant mean differences?	Yes, T-stat > T-critical	Yes, T-stat > T-critical	Yes, T- stat > T- critical	Yes, T-stat> T-critical	No, T-stat < T-critical	Yes, T-stat> T-critical
Practically significant difference?	No, effect size < 20%	No, effect size < 20%	Small, effect size ~ 20%	Yes, Large effect	No, effect size < 20%	Yes, very large effect

for significant differences between the groups. For the test and control groups there is a statistically significant difference in CHEN 301 and 302 scores within each population [columns 2 and 3] and that difference is toward the positive for the test group and by roughly the same amount toward the negative for the control group as evidenced by the t-statistic for the difference between groups. The effect size is 18%, which according to Cohen's *d* 20% guideline shows at best small practical significance; however, we must also consider ABU grading criteria. For the test group there is an improvement of 13% from a mean grade of 45% (D) to 51% (C), while for the control group there is a 21% decrease from 56% (C) to 44% (E). The letter grades of C, D and E correspond to course GPA contributions of 3, 2 and 1, respectively on a 5-point scale and hence the effect size is substantial when viewed in this light.

The change in semester GPA from first to second semester within the control group (column 4) was found to be statistically and practically insignificant. This suggests, on the average, a situation of class stasis. In sharp contrast, the practical significance of the improvement within the test group is very large. Figures 5c&d offer strong pictorial reinforcement of these contrasting scenarios. In fact there is a computed 243% practical significance in GPA improvements between the two populations (see Table 2, column 7) which amounts to better than 80% non-overlap between the two populations. We suggest that the implementation of the new pedagogy in CHEN 302, which hinges on the 7 PGPs [3, 28] resulted in a spread effect to other classes. We could intimate that the overall semester GPA improvement within the population resulted from carryover of a team spirit to other coursework that included better peer interaction, faculty-student interaction, and higher inquisitiveness of the students. We aim to pursue this angle in further batches of students to confirm trends and probable causality.

While these preliminary data along with faculty observations are encouraging we must insert some strong qualifying remarks. It is difficult to say that the improvements that coincided with the HAL implementation were solely due to HAL. Perhaps there were other factors influencing the students in prior years such as turmoil at the university, or perhaps an analysis of other student populations will reveal random variations of similar magnitudes as those observed for the HAL semester. Nevertheless, the trends are consistent with what is seen in the literature. For example, Crouch *et al.* [7] have shown that when students talk to each other they translate information into language they understand and that this is not always true when they hear the material from an expert. Even when an expert performs in-class demonstrations, students still learn less than when they discuss the demonstration themselves. Also, Pauk [46] shows that students who study together do better: "Friends learning a subject together often share the same difficulties and can thus enlighten one another very effectively". It is precisely these kinds of student-to-student activities that were brought up in the faculty interviews, and this is in sharp contrast to the competitive environment that has typically existed where students were known to even hide textbooks from each other.

3.6 Assessments by DLM/HAL Adopters

The implementation of the new HAL/DLM pedagogy in ABU by co-author Van Wie during his Fulbright exchange is a radical shift from what most ABU lecturers are used to. The assessment by the Nigerian co-authors in terms of how the new pedagogy can help solve educational problems in Nigeria is enlightening. Of course, use of the approach will also have similar implications throughout Africa as well as other developing nations. Following are our conclusions:

3.6.1 Exposure to industrial equipment

Most Nigerian students are not exposed to industrial equipment operations to the same extent as their counterparts in more developed nations, as the students lack the same opportunities to go on paid industrial internships (a consequence of African industrial underdevelopment) and the universities often do not have the budgets to buy and/or maintain larger scale unit operations laboratory equipment. Hence, the miniaturized DLM helps bridge this gap.

3.6.2 Practicality

The portability of the DLMs when compared to traditional laboratory equipment enhances easy movement from class to class and the small size makes them easy to use in the limited space in most African classrooms. This design allows DLMs to be placed on most classroom desk surfaces without resulting in tripping hazards from power cords or water hoses being run to or from the module. We also note that because the DLM reaches steady state quickly it creates a particular advantage for the introduction of HAL when using a small number of units for large 100–300-student Nigerian classrooms given the associated time constraints encountered in passing so many groups through the DLM learning stations.

3.6.3 Versatility

The DLM is versatile due to the availability of a wide spectrum of plug-in cartridges and therefore, when commercially available, it is expected to be significantly cheaper than conventional laboratory equipment. The DLM with six plug-in cartridges:

(1) shell and tube;
(2) double pipe;
(3) extended area heat exchangers;
(4) Venturi and orifice meters;
(5) packed/fluidized beds;
(6) accessories.

are expected to cost about $8,000 when commercialized. This is much cheaper than currently available commercial bench-scale equipment which just for a heat transfer bench, heat exchanger, and data acquisition system currently used at ABU can cost as much as $25,000– $30,000. The maintenance is expected to be a function of usage with an upper estimate of 5% of usage time. The parts are very durable and it is expected that a new electronics package will alleviate problems we have had with solder joints and will also be readily replaceable as an entire unit.

Given the cost, we could ask why not replace the hands-on aspect with a video or a single-team demonstration followed by sharing of results. The authors feel this may not be ideal considering the experiential, hands-on nature of most engineering functions. Perhaps an extreme example would be to suggest a hungry student watch a cartoon of someone eating a burger with the hope that the said student's hunger will be assuaged. Moreover, we acknowledge the work of Crouch *et al.* [7] mentioned earlier that shows demonstrations are only effective when students actively participate in them. In this study aptly titled "Classroom demonstrations: Learning tools or entertainment?", the authors found that learning is enhanced by increasing students' engagement and that students who predict the demonstration before seeing it display significantly better understanding.

3.6.4 Suitability for Lengthy Class Periods

The average student is weary of the traditional lecture format where the lecturer reads out theory upon "abstract" theory with the result that "half" the students are drowsy halfway through a lecture that in Nigeria typically takes 2–3 hours. The extended lectures given once per week rather than every other day are important for the limited number of faculty available as many of them are conducting research for higher degrees at other locations where research equipment is more available. In addition there is a short supply of PhDs so universities hire short-term lecturers from other universities to come in and teach short courses. Conversely, the HAL method stimulates the students' curiosity and holds their attention even over the prolonged classroom periods.

3.6.5 Student accountability—staying on task

Because lecturers circulate, interacting with groups during an HAL implementation, the students are motivated to participate rather than work on other assignments unrelated to the class [47]. This problem is inherent in the Nigerian system—students are typically required to take 22–25 credits per semester, in contrast to US practices where the credit numbers typically range from 15–18; because of the large number of credits students find it more challenging to find time to do their homework and therefore use class time to do so. We find that despite the underlying temptation to use class time for other purposes, with HAL the students are enthused about the subject at hand and do not want to miss out on the excitement of working together.

3.6.6 Facilitates group work

Group activities in the educational curriculum of most developing nations, especially Nigeria, is somewhat restricted. Until recently the norm has been a rather narrow and individualistic mode of learning where every student works independently for the most part. In fact this deplorable situation gave rise to the so-called 'OYO' ('On Your Own') syndrome where every student learns his or her own way with the attendant individual misconceptions and limited learning. However, in view of the current global trend where engineering designs are a result of team projects, a paradigm shift is necessary for developing nations if they are to become globally relevant. The construction of the DLM and in fact almost any piece of engineering laboratory equipment is such that one individual cannot operate and record observations simultaneously, and much less do so quickly. In fact, because the DLM reaches steady state so rapidly this alone creates the necessity for a team approach. Furthermore, the new pedagogy incorporates all the PGPs including group work.

3.6.7 More comprehensive learning experience

The practical aspects of visualizing, touching, hearing, and hand manipulation of pilot scale industrial processes have all been until now relegated to a separate laboratory experience. Furthermore, while current educational methods focus on individuals learning a narrow set of concepts, real world industrial problems are complex and solutions to these problems requires that engineers and scientists work in broad multi-talented teams. Hence, one would expect to see aspects of active [3, 48–52], problem-based [53], and cooperative learning [54–56] in such courses. Science and engineering education in other nations, especially developing ones, are therefore in need of incorporating these new and better pedagogies to train the current generation of students. This is in contrast to institutions such as WSU where the DLMs have previously been implemented [30]. Furthermore, DLMs foster the use of a more tactile or sensing learning environment, and reinforce the learning of "soft skills", such as teamwork, interdependence and mutual accountability desired for a successful engineering career. Student groups can make observations, collect data, and have a discussion about the system, as well as models and calculations that describe the system.

We concede that cognitive gains due solely to the equipment have not yet been confirmed by the CI instrument, but assert that gains in the affective domain which may well serve as motivation for cognitive gain can be readily inferred from the survey data. We plan to pursue thorough assessment of cognitive gains from using the DLM and the pedagogy, employing better controls so as to clearly elucidate and delineate gains in a higher/or different outcomes domain that is attributable to the equipment alone. We would assess how the DLM can promote skills acquisition and also how it can help students whose learning skills are skewed towards the visual and tactile. Also, we observe that averages, as have been used in reporting the cognitive gains, only give insight into what is happening in a general population and may mask the cognitive gains for individual students whose learning style is in sync with the equipment. To confirm or refute this we plan to study outcomes for individual students in future studies.

3.6.8 Mitigating the lack of utilities

Because of the prevalent, even daily electricity outages and lack of running water to most buildings in Nigeria and indeed other developing nations, the built-in battery and fluid reservoirs of the DLMs are very useful. Run time for the batteries exceeds the two hours of normal classroom time in Nigeria and the rapid approach to steady state (as was illustrated in the equipment performance section) allows the rotating of groups of students through DLM stations —a group can easily obtain data within 5–10 min, and several groups can use the same piece of equipment long before battery storage is depleted and before hot and cold water reservoirs equilibrate. The author notes an instance during installment and testing of a current commercial-brand bench-scale heat exchange experimental device in the Chemical Engineering laboratory at ABU; the installer had to stop because there was a sudden power outage. Meanwhile Prof. Van Wie's son, a Fine Arts major who accompanied him on the Fulbright, performed a similar experiment on the DLM and did not experience such a problem and finished an entire afternoon of experiments while the aforementioned technician was still waiting for power to be restored.

3.6.9 Enhancements

While the authors believe that the pedagogy as it stands is a good innovation, we would like to state that there is still room for improvement. In line with this WSU recently introduced a project-driven pedagogy using the DLMs as supporting equipment [35]. The targeted outcomes in this project-based class are Bloom taxonomy objectives such as analytical, problem solving, synthesis, and group skills. The assessments being used in this alternative approach include critical thinking and group process rubrics, problem solving, and synthesis ratings. We suspect that the problem-solving assessments would be a good way to evaluate the efficacy of the DLMs especially if the solutions require knowledge gained by practical hands-on experience.

4. Conclusions

The new DLMs are getting a warm reception and showing suitability for use in the Heat Transport course in the Chemical Engineering Department at

Ahmadu Bello University, Zaria, Nigeria. The system's onboard battery and hot and cold water reservoirs make it useful in infrastructural challenged environments. A technical analysis of the DLM shows a quasi-steady state temperature can be achieved in at most 24 sec at the lowest water flow rate (5 GPH) used in this study. We also estimated that a minimum of 48 students from 12 groups can have useful quality learning on a DLM over a one-hour period (half the standard class duration). This is important in view of the typically large classes encountered in Nigerian universities. Also, the DLM's simplicity obviates a long learning curve, and the attendant frustration that may cause students, so that groups can pass through the DLM hands-on learning station quickly and with ease.

HAL pedagogy when used simultaneously with the DLMs has positively impacted the learning experience of students. A two-way ANOVA shows the students improved conceptually by the same amount in both a lecture and a HAL setting. This suggests that replacing a conventional lecture with a hands-on active environment does not hinder learning that some may argue can only come through a lecture by a highly qualified instructor.

We could argue that the insignificant difference in gains in conceptual understanding between the HAL and lecture appears to obviate the need for extra investment in teaching equipment. However, we note that the Flashlight survey results make a strong case for use of the HAL / DLM pedagogy especially given how it has helped promote development of certain "professional skills" like team work, grasp of important facts, and persistence of concepts, visualization of ideas, peer interaction, and curiosity. An overwhelming 96% were of the opinion that they are better able to remember important facts, while 88% agree they have a more thorough understanding of ideas and concepts, and 94% said they are better able to visualize ideas. Further analysis of the survey in terms of the seven PGPs, upon which the survey is based, shows strong supportive evidence, with responses in the 80+% range, that the HAL / DLM pedagogy is highly effective in stimulating all seven practices. HAL has also provided the students with new and varied ways of self-learning and group learning which are in tandem with world-class best practice.

Survey responses of ABU Chemical Engineering faculty not only show that the new approach was well received, but corroborate the persistence of a group learning mentality among the students that extends to other coursework. Furthermore, there appears to be a cultural shift in teaching and learning philosophy among the faculty to the extent they now often include hands-on and active exercises in their respective classes.

The CHEN 302 and GPA improvement for the set of students who were exposed to the new HAL pedagogy over a previous set who were not is intriguing especially as the Flashlight and faculty surveys corroborate a systemic shift and spread effect toward team learning. However compelling this observation may be, we note that it could have just been fortuitous and therefore we plan to pursue this line of thinking to establish reproducibility and causality.

When taken collectively, the positive Flashlight survey data, equal gains in conceptual understanding between lecture and HAL/DLM use, development of other skills required in future practice, faculty enthusiasm, and apparent spread effect, the new HAL/DLM pedagogy is very attractive for use in classrooms of developing nations, especially when considering the relatively low cost and practicality of the DLMs. We intend to investigate conceptual aspects further by checking the suitability and alignment of our MCQ test to the hands-on aspect of the whole pedagogy package. We also intend to look into other more robust assessment tools, for instance, the worksheets and a Critical Thinking Rubric designed at WSU that could be in better alignment with the DLM.

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Baba Abdul obtained an MSc in Chemical Engineering from the Ahmadu Bello University (ABU) Zaria Nigeria in 2005. He has had some work experience in the chemical process industries, mainly crude oil refining and solids processing. He is part of the faculty at ABU and currently on leave to Washington State University to obtain a PhD that includes elements of Fluid Dynamics and Heat Transfer in Helicosymmetric channels, and Engineering Education.

Bernard John Van Wie completed his BS, MS and PhD and postdoctoral work at the University of Oklahoma where he also taught as a Visiting Lecturer. He has been on the WSU faculty for 27 years and over the past 13 years has focused strongly on innovative pedagogy along with his technical research in biotechnology. His recent Fulbright Exchange to Nigeria set the stage for receipt of the Marian Smith Award given annually to the most innovative teacher at WSU.

Jerome Tudela Babauta is currently a PhD student in Chemical Engineering at WSU whose work is sponsored by a NIH Biotechnology Training Program. He was recently sponsored by the National Science Foundation OISE Program as an exchange student to Nigeria.

Paul Brian Golter who designed the Desktop Learning Modules obtained an MS from Washington State University and is currently pursuing his PhD while working as the Instructional Laboratory Supervisor in the Chemical Engineering Department at WSU.

Gary Robert Brown obtained a PhD in Education from Washington State University in 1994 and is currently the Director for the Center of Teaching, Learning and Technology at Washington State University.

Raymond Bako graduated from ABU, Zaria in 1982 with B.A. Ed. (History); the University of Jos in 1988 and 2007 with MEd and PhD in (Philosophy of Education). He was a Fulbright Scholar at the University of Maryland, College Park in 1998/1999. He is a Senior Lecturer and has been teaching undergraduate/Postgraduate students since 1990. He is a member of the university Senate and the Coordinator of the new Department of Educational Foundations and Curriculum Studies (DEFACS). His research interests are in education theory, policy analysis, curriculum innovation, new teaching methodologies and higher education studies.

Abdulkarim Salawu Ahmed obtained his PhD in Engineering Materials from the University of Leeds, UK in 1992 and is currently the Head of Chemical Engineering Department at Ahmadu Bello University, Zaria, Nigeria. He has many awards, publications, patents and grants to his credit.

Emmanuel Goni Shide obtained an MSc in Chemical Engineering in 2001 and is currently a PhD student in Chemical Engineering from ABU, Zaria, Nigeria. He has several publications and two grants to his credit.

Fatai Olukayode Anafi holds MBA and MSc Mech. Engr., 1999 and 2001 respectively from ABU, Zaria, Nigeria. He has 18 years teaching, research and professional engineering practice experience. He is a faculty member of ME Dept. at ABU and currently working on a PhD studying the effect of flow and geometry parameters on impingement heat transfer.

Olasaju Olalere Olaofe obtained a Bachelor of Engineering Degree (First Class Honors) in Chemical Engineering at ABU in 2000 and a MSc and Professional Doctor of Engr. Diploma from the University of Twente, Netherlands in 2004. He lectured at ABU from 2006–2008 during which he served as the Assistant Examination Officer and later the Examination Officer. He is currently pursuing a PhD on Computational Fluid Dynamics of Multi-phase flows: Multi-Scale Modeling of Gas Fluidized Beds at the Univ. of Twente.