AC 2010-2416: BRINGING RESEARCH INTO THE CLASSROOM: CONCEPTUALLY NEW HEAT-EXCHANGE CARTRIDGE FOR CHEMICAL ENGINEERING EDUCATION.

Baba Abdul, Washington State University

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 petroleum refining and solids processing. He is part of the faculty at ABU. He is currently working on a PhD that includes elements of Fluid Dynamics and Heat Transfer in Helico-symmetric channels, and Engineering Education at the Washington State University, Pullman WA. 509-335-9625;davab@wsu.edu.

David Thiessen, Washington State University

David B.Thiessen received his PhD in Chemical Engineering from the University of Colorado in 1992 and has been at Washington State University since 1994. His research interests include fluid physics, acoustics, and engineering education.

Bernard Van Wie, Washington State University

Prof. Bernard J. Van Wie did his B.S., M.S. and Ph.D. and postdoctoral work at the University of Oklahoma where he also taught as a Visiting Lecturer. He has been on the WSU faculty for 26 years and over the past 12 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. (509) 335-4103 (Off); (509) 335-4806 (Fax); bvanwie@che.wsu.edu.

Gary Brown, Washington State University

Dr. Gary R. 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. 208-818-1413; browng@wsu.edu.

Paul Golter, WSU

Paul B. Golter obtained an MS from Washington State University and is currently pursuing his PhD while working as the Laboratory Supervisor in the School of Chemical Engineering and Bio-engineering at WSU. He is married with two children.509-338-5724.

Bringing Research into the Classroom: Conceptually New Heat-Exchange Cartridge for Chemical Engineering Education.

Abstract

There is a need for faculty to integrate their research and teaching activities. This call has become more strident especially within research universities. In fact, funding agencies such as the NSF are providing strong motivation to include educational components as part of the broader impact of research proposals. This paper describes an example of a new idea from the research lab in the form of a multichannel evaporator being brought into a classroom with an inductive learning environment for testing and analysis by the students. Hands-on activities with the equipment are designed to promote understanding of heat- and mass-transfer principles. The evaporators utilize novel open-coil capillary channels that are being developed for various applications including intensified processes. Activities, concept questions, and a teaching strategy continue to be modified to center on classroom implementation of this evaporator. Targeted assessment in the form of pre and post concept tests was administered but the results were not statistically significant. Students reacted positively to the opportunity to test a new system that cannot be found in textbooks.

Introduction

Despite numerous articles that report a weak correlation between technical research and effective teaching [1-3], a few studies have found a positive correlation between the two [4]. Astin in his monumental work reports that research-oriented universities in fact impact negatively on measures of student cognitive and affective development [5]. Astin attributed this to a low priority given to undergraduate teaching at such institutions. This low priority to teaching is also tied to faculty hiring and reward structure which is heavily skewed towards research output because of the dependence of most universities on external research funding [6]. Interestingly, universities and community colleges which have teaching as their primary goal are striving for more research output because they too want to attract external research funding [7].

Whether or not there is a widespread and strong synergy between research and education, the consensus among many stakeholders is that there should be [8-9]. The potential benefits to the various parties involved cannot be overemphasized [7]. Students can benefit by the satisfaction they derive from knowing that what they are learning in class is at the frontiers of knowledge. Faculty gain satisfaction from integrating their teaching and research functions. Universities, on the other hand, benefit when funding agencies and potential students see them as fulfilling their dual missions of research and teaching. This could translate into more funding from the former and more enrollment and retention of the latter.

Although there appears to be little correlation between research productivity and teaching effectiveness at the individual faculty level in current practice, Prince et al. [10] argue that there is the potential for a positive impact of research on teaching. The authors suggest that one possible way to strengthen the connection between research and teaching is to encourage the use of inductive teaching methods. The idea is to teach in a manner that emulates the research process. An open question is whether inductive teaching methods actually do facilitate the integration of teaching and research.

Limitations on the integration of teaching and research include inadequate methodology [11], curriculum constraints and the insufficient background knowledge of most undergraduates [12]. To effectively and seamlessly incorporate research into classroom activities therefore, it is imperative to emphasize just those aspects which can reinforce course content without putting too much strain on the curriculum and students, and to choose a pedagogy which does this engagingly [13]. In line with this, approaches that include problem-based, project- based [14] and inquiry-based learning [15], have been recommended as the best pedagogies for bringing research into the classroom [8].

We report on an example of bringing an idea from technical research in the form of a novel microchannel evaporator into an undergraduate classroom that is already using inductive teaching pedagogies [16]. The evaporator is a particular application of a new open-coil capillary channel on which fundamental studies are underway. Students are guided in a hands-on evaluation of the evaporators in a process that emulates what might occur in a research laboratory. The goal of these activities is to reinforce evaporation-related concepts, introduce the students to basic research procedure, and teach students synthesis and evaluation skills. We used a blend of guided inquiry, and hands-on active learning to engage the students [17]. Finally we discuss results of a conceptual test given pre- and post-class to try to measure learning gains.

Materials and Methods

Equipment description

The multichannel evaporator was designed as a plug-in cartridge for the Desktop Learning Module (DLM) system being developed at WSU to promote collaborative, hands-on, active, and problem-based learning of fluid and thermal sciences in engineering [18]. The DLM base unit provides fluid reservoirs, pumps, flow meters, temperature probes, and temperature and pressure displays in a compact platform (approximately one cubic foot). Interchangeable cartridges allow students to perform various fluid flow and heat-transfer experiments including experiments on miniature versions of industrially relevant heat exchangers [18]. Figure 1 shows three of the evaporators in operation on top of DLM base units. The evaporators consist of a rectangular array of 32 stainless steel springs. Each spring is 1/8-inch diameter, with a wire diameter of 0.013 inch and an interwire distance (pitch) of 0.026 inch creating channels that are 6 inches in length. The springs are assembled in an open rectangular frame with a transparent distributor at the inlet to ensure uniform flow distribution. The assembly is clamped on top of one of the two tanks of the DLM base unit and connected to the corresponding pump outlet via a hose and quick-connect coupler. Water flows from the distributor through the springs and falls back into the one-gallon DLM reservoir (Figs. 1 and 2). Surface tension prevents major leakage even though approximately 50% of the channel wall is open (the space between coils). The angle of the cartridge can be adjusted from vertical to horizontal. For a horizontal orientation the flow is capillary driven and the holdup of water in the channels is increased relative to the vertical orientation. A fan mounted on the rectangular frame blows air across the array of springs. Process temperature changes are monitored on the DLM's built-in electronic display. Flow rates up to 70 gallons per hour are possible and a cooling rate of 290 W has been measured with water starting at 39° C. The evaporators could also be used independently of the DLM system with simple gravity feed from a tank using a handheld temperature probe to measure temperature change between feed tank and evaporator outlet.

These cartridges, designed by the researcher (Thiessen) were constructed in the WSU instrument shop at a cost of $300 per cartridge, bringing the total cost to $900 for the 3 units that were used in this class. The open-coil capillary channels implemented in the evaporators have potential applications in intensified small-scale processes because of their high surface area density and in microgravity phase separation and micro heat pipe applications because of their capillary-flow capabilities. Fundamental studies of the capillary stability [19] and flow properties [20] of the channels are ongoing.

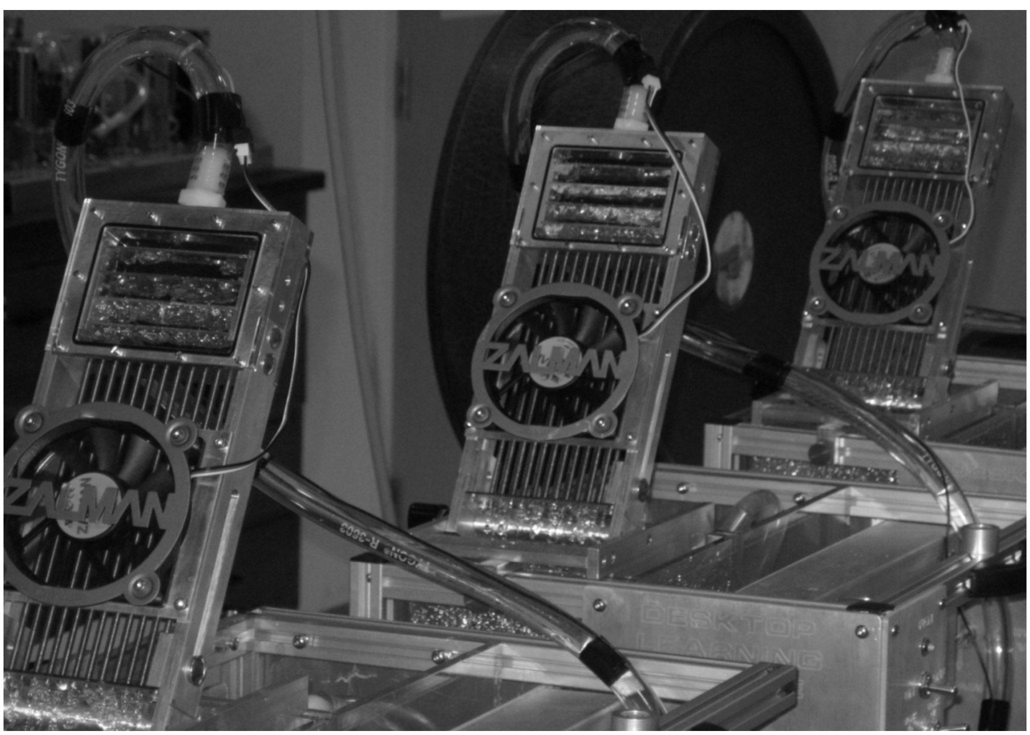

Figure 1. The new evaporators mounted on Desktop Learning Module bases.

Activities design

Activities were implemented during one class period of ChE 332, Fluid Mechanics and Heat Transfer, at WSU during the Spring 2009 semester. The activities for this 50-minute period were designed based on the principles of backward design [21] and guided inquiry. 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.

The 12-student junior class was typically split into 3 groups of 4 students each for group learning activity. It should be noted that they had hands-on learning experiences with miniature conventional heat transfer and flow metering devices earlier in the semester as part of the fluid mechanics and heat transfer elements of the class. The students had also taken a prerequisite course during a previous semester on the fundamentals of transport phenomena (momentum, heat and mass).

In deciding what we wanted to achieve by bringing this research into the classroom, we felt it was desirable to target higher level outcomes in the revised Bloom's taxonomy [22]. Since the students are being asked to understand a new process from a fundamental point of view some of the activities are designed to promote the Bloom's level outcome of *creation* (*synthesis*). Other activities promote the outcomes of *analysis* and *evaluation*. Learning outcomes for the course were stated in the syllabus. Language from the syllabus most relevant to the present activity was:

> The ability to think critically and creatively and to apply quantitative reasoning skills will be evidenced by your ability to:
>
> Analyze an existing heat exchanger and be able to predict its performance for specified inlet fluid properties and flow rates.
>
> Explain, in terms of fundamental principles, how a heat exchanger works.

Performance improvement from pre to post concept tests, in-class questions, group discussions, appropriate analysis of a short in-class experiment, and prediction of heat-exchanger performance from fundamental engineering principles were deemed to be adequate evidences of achievement of the learning objectives of this class.

At the previous class period a reading assignment was given including a set of notes on the principles of evaporation with forced convection. For the activities proper, a five-question pre-test on evaporation concepts was first administered. Appendix 1 details the full set of questions.

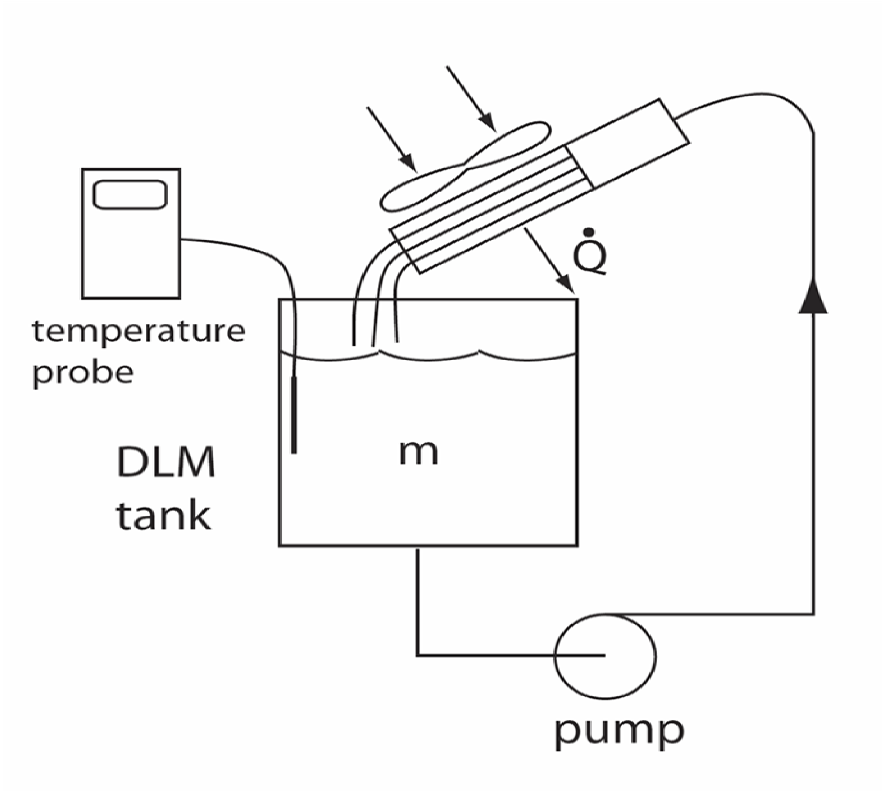

Figure 2. The process flow diagram.

After the pre test, the researcher (Thiessen) gave a short (~15 minute) guest lecture on the principles behind evaporative heat transfer with forced convection. He first introduced the students to the novel evaporator and its potential applications. He then explained how the evaporator worked and pointed out that, for the purpose of analysis, it could be treated as an array of cylinders of water with air flowing normal to them. An approach for analyzing the thermal performance of the evaporator and for predicting its performance from engineering principles was discussed with reference to the notes and readings from Thomson [23] and from McCabe, Smith and Harriot [24] that the students were asked to study preparatory to this class.

After the lecture, the students were split into groups. Each group was then provided with a DLM base unit, an evaporator cartridge, and a set of instructions and questions in a worksheet. They were asked to estimate the wet bulb temperature from measurements made by the instructor during a demonstration and to suggest why the temperature on the wet bulb thermometer stopped dropping after a while. Water at different temperatures were then assigned to different groups and they were asked to take temperature readings at regular intervals for 10 minutes with a water flow rate of 74 mL/s (70 gph) and an air speed of 1 m/s (as measured by an anemometer). Figure 2 is a schematic of the process. Following the data taking, the students worked on several conceptual questions that prepared them for the analysis of experimental data and evaporator performance predictions that they would be doing as homework. The evaporator analysis involved finding the slope of the temperature versus time graph near time zero along with the known mass of water in the process to calculate the initial rate of heat loss from the water. They were also asked to predict the rate of heat loss from the engineering principles discussed in the lecture and compare this to the measured rate.

At the end of the class, the same questions as in the pre-test were administered as a post-test to gauge student learning gains due to the activities.

Results and Discussion

Pre and post quiz: The results of the pre and post test are summarized in Table 1. The sample size in this particular class (N=8) is too small to be able to draw statistically relevant conclusions from our data but the results are perhaps suggestive of the following interpretation. The first question tested students' understanding of the enthalpy balance on a drop of water. The targeted notes the students were assigned to read before class discussed the enthalpy balance in detail with a schematic that showed fluxes of heat and matter into and out of the interfacial region. All 8 students got this question correct on both the pre and post tests. The second question tested their understanding of wet-bulb temperature. The wet-bulb temperature was measured in class by the instructor as a demonstration and the students recorded this for use in their data analysis. The students also answered a worksheet question during class asking them to explain how the wet-bulb temperature is measured and also asking them to explain why they need to know it (anticipating the more in-depth analysis they would do outside of class). There were 6 correct responses to this question pre and post, however only four students were correct both times while four changed their responses. The third question was most directly relevant to the hands-on activity with the evaporators. This question is perhaps getting at the kind of knowledge that can best be conveyed by the hands-on experience. Two students changed from incorrect to correct responses on this question. The fourth and fifth questions required a more in depth understanding that was perhaps not reinforced by the hands-on activities. There were few correct answers on either question, and the scores actually decreased on the post test.

Table 1: Pre- and post-test scores for each question on the test.

Question	N	Pre-test correct	Post-test correct	Change
1	8	8	8	0
2	8	6	6	0
3	8	5	7	+2
4	8	3	1	-2
5	8	1	0	-1

Conclusions and Future Plans

From the foregoing preliminary analysis, we deduce that the students found the activities built around the new evaporator to be both challenging and rewarding. We find that the one question that was most strongly related to the hands-on activity (question 3) showed improvement, although this is not statistically significant. Questions 4 and 5 however, revealed sharp misconceptions and we intend to reexamine them for the purpose of formative assessment. It is unclear whether targeted pre and post tests can measure the effect of an intervention over a single class period. Part of the potential benefit of the kind of hands-on activity studied here would come from the more in-depth analysis of the process that the students were asked to do as homework. It might be expected that students would be more highly motivated by an assignment in which they have real-world data that they took themselves to compare to their predicted heat-transfer rates. It might be better to give the post test after the homework is turned in. The conceptual questions used as pre and post tests in this study were produced by the researcher to be somewhat targeted to the notes and activities used in class and have not been validated. Future work should try to identify actual student misconceptions about the process and underlying mechanisms to use as distracters in the multiple choice questions. A future implementation is planned at a Nigerian university where sample sizes are significantly larger (N~150-300).

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Appendix 1

1. A drop of water initially at room temperature rests on a perfectly insulating tabletop. The humidity of the surrounding air is low.

A. The water will not evaporate because no heat can come from the tabletop or from the surrounding air, which is at the same temperature as the drop.

B. Water will evaporate if the equilibrium partial pressure of water vapor at the drop surface exceeds the partial pressure in the air away from the surface.

C. The drop will spontaneously heat up as evaporation proceeds, driving even more evaporation.

D. The drop will not evaporate because the drop and surroundings have the same temperature, which means the same concentration of water vapor.

2. True or False: When the wet-bulb temperature equals room temperature the air is saturated with water vapor.

3. An evaporative cooler is being used to cool a tank of water by making contact between flowing water and moving air. What would be the most effective way to increase the rate of cooling?

A. Double the contacting surface area between water and air.

B. Double the flow rate of water.

C. Double the speed of the air flow.

4. Consider two spherical drops of hot water with identical initial temperature falling in dry cool air such that the Reynolds number for airflow past the drops is identical. If drop 1 has a diameter D and drop 2 has diameter 2D, the relative rate of change of temperature will be

A. identical for both drops because the heat- and mass-transfer coefficients are identical.

B. impossible to decide without more information.

C. greater for drop 2 because although it has more mass, it also has more surface area.

D. greater for drop 1 because although it has less surface area, it also has less mass.

5. A cup with perfectly insulating sides and bottom contains water initially at 18°C and is open to the air on top. Room temperature is 22 °C and the wet-bulb temperature is 14 °C. Blowing room air across the top of the cup will

A. warm the water in the cup up to room temperature because of heat transfer from the warmer room air.

B. cool the water down to a temperature somewhere between 14 and 18°C where convective heating and evaporative cooling balance.

C. cool the water down to 14°C eventually.

D. cause the water temperature to reach a value that depends on how fast the air is blowing.