Implementation of a Modular Hands-on Learning Pedagogy: Student Attitudes in a Fluid Mechanics and Heat Transfer Course

J.K. Burgher D. Finkel O.O. Adesope B.J. Van Wie
Washington State University

Abstract

This study used a within-subjects experimental design to compare the effects of learning with lecture and hands-on desktop learning modules (DLMs) in a fluid mechanics and heat transfer class. The hands-on DLM implementation included the use of worksheets and one of two heat exchangers: an evaporative cooling device and a shell and tube heat exchanger. A survey was administered at the end of the course to assess student attitudes and self-identified conceptual understanding for the (DLMs) and lecture. Results indicate that 72% of students receiving the hands-on DLM treatment thought it helped more than lecture; of those receiving lecture, 40% thought that it helped more than the DLM to learn heat transfer concepts. With respect to conceptual understanding, 72% of students agreed they understand and can apply principles related to heat exchangers well, with 28% unsure of their own conceptual understanding. Nearly a third of the free responses indicate students also want lecture in the classroom, with a corollary that the DLMs are only effective after a foundation in heat transfer has been established. Thus, one practical implication of the study is that lectures should first be used to explicate concepts and provide a good foundation that can then be developed further through the use of modular DLMs.

1 Introduction

1.1 Background

For the past several decades, lecture has been a cornerstone of quality education and an integral part of teaching pedagogy. However, in recent years the engineering community has found its graduates need more than technical skills to successfully serve the needs of their employers and greater society. Demand for increased professional skills including teamwork and communication, broader knowledge of ethics and economics, and the ability to work with colleagues from varying backgrounds has been the resounding message from industry. Additionally, when students receive lecture as a teaching pedagogy, they often fail to retain concepts long-term and do not build integrated models of the engineering concepts (Abdul et al., 2011; Burgher, Thiessen, & Van Wie, 2013; *Educating the engineer of 2020; Adapting engineering education to the new century,* 2005).

To meet these demands, academics must be especially cognizant of their teaching pedagogies and the amount of content knowledge students retain long-term. Several approaches have been taken to cultivate professional communication and teamwork skills, from demonstration-mode pedagogies to flipped classes, and classes where individual team members are responsible for leading interactive discussions while following a guided inquiry worksheet (Fulton, 2012). This spectrum consists of active learning strategies, with variations of collaborative or cooperative learning included in the structure (Prince, 2004). Hands-on components can encompass modules or representations, some of which offer virtual engagement with the material and others that consist of 3D equipment like circuit boards or other engineering materials made usable for students (Jones & Issroff, 2005; Jones, Kehle, & Bray, 2004). Studies that investigate the effectiveness of different pedagogies have been summarized by Bligh, who reports lectures are not meant to promote thought or change student attitudes regarding a particular subject. Assessing the literature on student attitudes, he found lectures are less effective 47% of the time, no change exists 41% of the time, and lecture is more effective at changing student attitudes than the aforementioned pedagogies just 11% of the time (Bligh, 2000). Thus, if the goal of a course is to promote thought, change attitudes, or develop skills, lecture is not the pedagogy to use; Bligh notes lectures are effective to communicate information only.

Exploring other studies can offer insight into effective pedagogies that document positive student attitudes. Yadav used a case study implementation in mechanical engineering to determine the attitudes and conceptual changes students experienced with the implementation over traditional lecture. While he did not show statistically significant results between traditional lecture and the case study implementation, student attitudes towards the case study were positive because it helped them better engage with their coursework and brought realism into the classroom (Yadav, Shaver, & Meckl, 2010).

Clark, DiBiasio and Dixon (1998) implemented active learning and group projects in the sophomore year of the chemical engineering curriculum (called spiral curriculum) aimed at increasing teamwork and professional skills. The study showed immediate gains by students participating in the spiral curriculum on both teamwork skills and overall understanding of engineering concepts. Additionally, students that experienced the curriculum starting in the sophomore year performed better in junior and senior level chemical engineering courses (Clark et al., 1998). Lee and colleagues used an implementation that includes a computer simulator designed to connect students with a more realistic engineering experience, by extending an engineer's work and laboratory to increase student motivation that allows students to better visualize processes, and provides an interactive learning environment. Conclusions indicate the simulators increase student grades, support an active learning environment and enable students to problem solve more effectively, which provided a channel for them to learn and retain deeper engineering concepts (Lee, McNeill, Douglas, Koro-Lyungberg, & Therriault, 2013).

These findings support the use of pedagogies other than lecture because they often result in positive student attitudes, even if statistically significant conceptual change is not demonstrated. In this study we explore student attitudes about classroom implementation of miniaturized chemical process industry equipment and accompanying worksheets. The design and implementation of the hands-on active learning sessions was informed using student-centered rather than teacher-centered theoretical frameworks. The focus here is more on detailed implementation strategy and student attitudes, while a detailed analysis of student conceptual gains will be the subject of a separate paper focused on these aspects.

1.2 Theoretical framework

Use of hands-on active learning components in this study allows the incorporation of the Seven Principles for Good Practice espoused by Chickering and Gamson (1987), an accommodation of the full array of learning styles (Felder & Silverman, 1988), and dual coding theory. The seven principles of good practice are to (1) encourage contact between students and faculty, (2) develop reciprocity and cooperation among students, (3) encourage active learning, (4) give prompt feedback, (5) emphasize time on task, (6) communicate high expectations, and (7) respect diverse talents and ways of learning. To promote the seven principles and enhance appreciation of diverse learning styles, the class was organized into teams, which facilitates cooperation among the students and encourages them to respect diverse talents and ways of learning. Sessions were arranged so time was spent with the team on the hands-on pedagogy as opposed to lecture, which encourages contact between students and faculty, promotes active learning, and emphasizes time on task. Additionally, high expectations were emphasized to help students think beyond equations and formulas and understand how and why concepts integrate to form a holistic model of the physical system. This was particularly emphasized through activity worksheet discussion items and exam questions aimed at probing for higher cognitive processes rather than memorization or rote calculations (Chickering & Gamson, 1987).

An empirical example of directed discussion that stems directly from the formulated worksheets includes the area of heat transfer that occurs in the shell and tube heat exchanger. Students discuss the area, write the formula, and indicate where on the shell and tube desktop learning module (DLM) the heat transfer occurs. Exercises like this are designed to help students form mental connections between the concept material they are learning and the miniaturized DLMs they use. A team project was also assigned where students define a hypothetical human or environmental need with designated constraints and apply and integrate concepts within that context to generate, evaluate and optimize a solution (Abdul et al., 2011; Golter, Van Wie, & Brown, 2007).

Integrating the Seven Principles and ensuring the pedagogy caters to a breadth of learning styles can encourage academic success for undergraduate students. Felder found most science students favor a visual learning style; thus, designing pedagogy for implementation in a chemical engineering classroom that favors visual learning should be advantageous to student academic success. However, Russian notes that while students have a preferred learning style, they can also comprehend and learn information when taught with methods that accommodate a different style. In addition to visual learners, audio, read-write, and kinesthetic learning styles also exist (Felder & Silverman, 1988; Russian, 2005).

More contemporary educational research that focuses on harnessing different modalities for learning has been explained by Mayer's cognitive theory of multimedia learning (CTML) (Mayer, 2005). This theory has three fundamental assumptions: (a) working memory has separate systems for processing verbal and non-verbal information, both of which are partially independent. This assumption is grounded in earlier work on dual coding theory (Paivio, 1991). These are also called the auditory working memory and visual working memory, respectively. As shown in Figure 1, Paivio's dual coding theory posits two different memory representations for verbal and visual information and that connection between these representations afford easier retrieval of information and consequently enhances learning; (b) each of these two working memory systems is limited in its processing capacity (Chandler & Sweller, 1992; Mayer, 2009; Moreno & Mayer, 2002b; Van Merriënboer & Sweller, 2005); and (c) learning from both verbal and visual materials occurs when relevant information in each mode is selected, organized, and integrated across systems (Mayer, 2005; Paivio & Clark, 1991). CTML hypothesizes that student learning and attitudes will improve when they learn with both visual and verbal materials that reinforce each other.

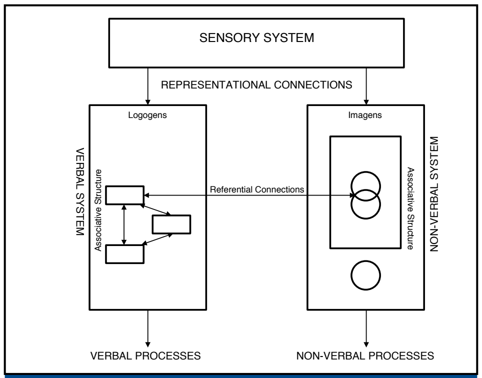


Figure 1: Schematics of Dual Coding Theory.

These three principles or theories form the foundation for the pedagogical design of this study; the specific use of Chickering and Gamson's Seven Principles, learning styles, and dual coding theory, also referred to as Mayer's cognitive theory of multimedia learning, have been incorporated into this study. It is important to note that student attitudes towards a given pedagogy can also impact the effectiveness of the pedagogy in the classroom. Understanding how students receive the pedagogy can inform future experimental designs and improve the effectiveness of the pedagogy for student success (Besterfield-Sacre, Atman, & Shuman, 1998); therefore, student perspectives as indicated through survey responses are strongly weighed in this study to predict better use and implementation strategies in the future.

1.3 Research Questions

This study was driven by two primary research questions: (1) what are student attitudes towards the hands-on active learning implementation of modular miniaturized systems in a fluid mechanics and heat transfer classroom? and (2) based on student experiences with the hands-on active learning and lecture pedagogies, how do they perceive their own conceptual understanding regarding the two modules tested in this study: the shell and tube and evaporative cooling heat exchanger?

2 Methods

2.1 Materials

The equipment used in the classroom was developed as part of a 17-year research effort to design and fabricate hands-on learning modules with base units and accompanying interchangeable cartridges to communicate chemical engineering concepts. This implementation leveraged the visual aspect of CTML by utilizing two heat transfer cartridges: a miniaturized shell and tube heat exchanger (Fig. 2) as well as an evaporative cooler (Fig. 3). These cartridges connect to a base unit with two reservoirs for hot and cold streams as well as a readout screen for temperature display. The shell and tube snaps into the base unit with counter-current flow streams and the evaporative cooler sits on top of the reservoir, with a stream flowing from the reservoir through the cooler.

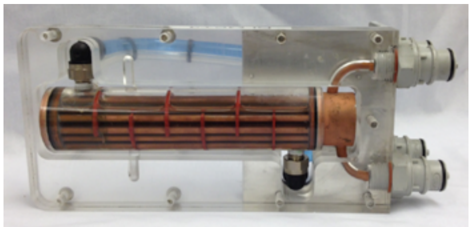


Figure 2: Shell and Tube cartridge.

Figure 3: Evaporative Cooling cartridge.

The DLM base and cartridge systems were fabricated in collaboration with the Washington State University (WSU) machine shop. The specific system arrangement represents the second generation of DLMs developed by the group. Fabrication proceeded by fitting fiberglass over a mold specially made for the base unit from schematics produced using Mastercam® software available in the machine shop. Mastercam® was also used to design the modular snap-in shell and tube heat exchanger, and evaporative cooler shown in Figures 2 and 3. The shell and tube system has a dollar-bill sized 5.7" length and 1.25" diameter, contains 24 copper tubes of 1/8" OD, 1/16" ID (BWG No. 22), a 0.19" tube pitch in a triangular arrangement, and a 0.83" baffle pitch, and is a 2:1 style, i.e., two tube pass one shell pass arrangement, and its performance is described in some detail in a previous publication by the group (Coon et al., 2011). The evaporative cooler was developed as a broader impact aspect on an NSF grant and consists of 32 springs of 1/8" diameter in a 0.25 in pitch triangular pattern, stretched to provide a 50% gap across the surface when fitted into a 5.5 long casing (Abdul, Brown, Thiessen, Golter, & Van Wie, 2010). Onto the evaporator is mounted a 3" fan (Zalman Tech. Co., Korea) that provides air flow causing water to evaporate at the air-liquid junction as air passes by the springs through which water is pumped and otherwise held in the springs by capillary action. Within the base unit mold are two circular openings for fluid flow reservoirs, with 8.3 W centrifugal pumps (Model MCP 350, Rouchon Industries, Inc., Swiftech™, Signal Hill, CA) installed and connected to two 0–40 GPH range rotameters controlled by adjustable needle valves (King Instrument Company, Garden Grove, CA). The units operate with 14 V batteries and have an OLED screen, displayed in Figure 4, specially designed and programmed by Digilent, Inc. (Pullman, WA, now a subsidiary of National Instruments) that displays temperatures from thermistors located within snap-in ports at the fluid entrances and exits of the shell and tube heat exchanger, and at the entrance of the evaporative cooler. This readout screen can be viewed in Figure 4.

The basic DLM concept has been commercialized and systems are available for purchase from the British teaching equipment company Armfield, Ltd. (Ringwood, England). The Armfield design includes several heat exchanger and hydrodynamic systems and the base unit changed to have a single reservoir platform, with similar receptacles for cartridge snap in. The shell and tube heat exchanger is available for purchase at a cost of $2,100 and base units are $3,235. Because of the change in design, the shell and tube cartridge needs two base units for operation, one for hot and a second for cold water. At this time, the evaporative cooler is not yet available for purchase from Armfield, Ltd.

Figure 4: OLED screen display as installed on the WSU DLMs.

The main concepts emphasized with each hands-on DLM session were also communicated via lecture for the control session. Equally as important as the equipment are accompanying preparatory quizzes, worksheets and learning materials for each of the respective heat exchangers. These are all available for both the shell and tube and evaporative cooler in the appendix. The preparatory quizzes were written to give students a theoretical understanding of heat transfer concepts before performing experiments on the DLM, while worksheets used alongside the shell and tube and evaporative cartridges were designed to communicate the same conceptual information as the lecture conveyed. Concepts covered in the supporting materials are represented in Table 1, which describes the learning outcomes associated with each heat exchanger. Additionally, while the instructor and TAs were present during the class, the worksheet was designed to lead the students through the experiment and guide them in collecting real-time data based on changing experimental parameters for each cartridge. The main concepts emphasized with each hands-on DLM session were also communicated via lecture for the control session.

The development of the worksheets and DLMs was guided by sound theoretical and empirical rationale. For example, the worksheet complements the use of DLMs and was written to promote discussion among users, especially when they are working with visual equipment (DLMs).

2.2 Implementation

A within-subjects design was used with participants that included 41 chemical engineering students from a 2-credit junior (third year) fluid mechanics and heat transfer course from Washington State University. A total of 12 women and 29 men were divided into teams of 5 with one team of 6 to form two sets of 4 teams each, one set which had a hands on activity for the shell and tube cartridge and a lecture for the evaporator cartridge, and the other set with the reverse set of pedagogies. The teams were balanced for ability based on GPAs, each having two members from the highest tier in the 3.5 – 4.0 out of a maximum of 4.0 range, one or two from the lowest tier of 1.9 – 2.6 range and two or three from the mid-range tier of 2.6 – 3.49. Assignment of team members was decided by the professor, with some input from the students who were asked to provide a list of eight individuals who they wouldn't mind having as a team member, though some did not choose to provide a list and therefore considered to have complete flexibility when considering team member preferences (Jones, Antonenko, & Greenwood, 2012; Thomson et al., 2003). The professor assigned groups with some degree of randomness making sure everyone had at least one member from their list and was able to do so even when lists consisted of some number of choices less than eight. The professor also considered gender and nationality seeking to make sure persons didn't feel like they were the only female or international on a team.

Prior to the hands-on group learning session, students completed the preparatory quiz associated with each cartridge and upon coming to class, the quizzes were submitted and group members were required to sit in close proximity and progress through the worksheet as a team. The classroom for the course had moveable tables and chairs so students could gather around the DLM and cartridge for viewing. This spatial feature better facilitated communication and discussion within the teams as well as encouraged participation by all members (Simonson & Shadle, 2013). At the conclusion of the class session the team turned in one worksheet; this allowed one team member to act as transcriber and other members to engage and discuss conceptual information as the experiment progressed. The deadline for the worksheet engendered motivation among students to work together to complete the task well and arrive at a written product that resulted from group consensus.

2.2.1 Implementation Logistics

Classroom

The DLMs and associated activities are designed to completely replace lecture; this designation results in the time taken for class, in our case 50 minutes, for the students to interact with and complete the real-time DLM experience and worksheet. Immediately upon entering the classroom, students must turn in their preparatory quiz that accompanies a particular DLM cartridge unit. This quiz is designed to give students a theoretical understanding of the concepts in the experiment, ensuring they have a baseline understanding of the work before entering class.

Shell and Tube Heat Exchanger	Evaporative Cooler
Shell and Tube Principles: Flow pattern, log mean temperature, cross vs parallel flow, resistances in series, log mean temperature correction factor, heat exchange area	Evaporative Cooling Principles: Mass and heat transfer, wet bulb temperature, psychometric charts

Table 1: Heat transfer concepts communicated via lecture and DLM sessions to students.

Attitude towards DLM	Hands-on group learning helped/would have helped more than lecture to understand and apply principles related to shell and tube heat exchangers (evaporative cooling).
Attitude towards Lecture	Lecture helped/would have helped more than hands-on group learning to understand and apply principles related to shell and tube heat exchangers (evaporative cooling).
Conceptual Understanding	How well do you believe you understand and can apply principles related to shell and tube heat exchangers (evaporative cooling)?

Table 2: Questions used in the survey administered to students.

Additionally, over the course of the class professors and TAs are available for questions and to keep students on task, it is required of groups to turn in one worksheet at the end of the class session, which encourages them to stay on task and complete the work.

Survey

For the study, a survey was administered at the end of the course. Each of the two groups, interacted with one of the heat exchanger DLMs, one with the shell and tube and one with the evaporative cooler, and had lecture for the corresponding implementation. This timing ensured students had the opportunity to compare their own experiences between the two instruction modes to answer the survey questions. This structure is critical for the survey relevancy, as students need to be able to differentiate between the lecture and hands-on group modes of learning.

2.3 Assessment

The survey design included two components: Likert multiple choice questions specific to student attitudes and self-identified conceptual understanding for each of the shell and tube and evaporative cooling cartridges as well as a free-response question asking students for suggestions on how to improve the hands-on group learning. The questions on student attitudes were asked to determine if students thought that hands-on learning helped or would have helped more than lecture (and vice-versa) and the free-response question was asked to solicit students' ideas of how to improve the implementation. Secondly, the conceptual understanding component was included to examine the degree to which the hands-on DLM experience helped student learning. The questions used in the survey are in Table 2, with items in parenthesis identifying different versions of each question for both the shell and tube and evaporative cooling concepts.

The survey was constructed and administered via Skylight, an online survey system designed and formerly operated by Washington State University, and used for course evaluations and surveys (Longo, Valiani, Lanza, & Liang, 2013). The total response number was N = 33, an 87% response rate. While a large percentage of students took the survey, the sample size was not large enough to run a statistical analysis on the results; therefore no statistical information is included in the remaining discussion. Specific identifying information was asked of each student to ensure only students enrolled in the course had the opportunity to complete the questionnaire. While the system differentiated the students before entering the survey, the report only gave responses to questions asked without supplying information that would identify individual students. Thus, we trust that student responses provide a good representation of their attitudes toward the course as this feature allows students to maintain complete confidentiality. There was no time limit for the survey; therefore students could give ample thought to their responses.

The results from the survey were broken into two categories representative of the survey structure. The multiple choice questions were analyzed based on their responses to questions on a five-point Likert scale. Results were tallied and compared between the hands-on DLM and lecture experiences for both student attitudes and conceptual understanding. The survey correlated to a rating range from 5 for strongly agree to 1 for strongly disagree. The other selections between these two, highest to lowest, are agree, unsure, and disagree.

3 Results and Discussion

3.1 Attitude

Student attitudes, as identified by responses to questions 1 and 2 from Table 2, towards both the hands-on DLM experience and lecture are represented in Figure 5. A majority, 72%, strongly agree or agree the hands-on experience helped or would have helped their ability to apply principles related to heat transfer processes, while 17% are unsure, and 11% indicate they did not prefer the hands-on treatment. Hence, the survey shows strong support for a team learning environment centered on use of a base unit with miniaturized industrial equipment in the form of interchangeable hands-on learning cartridges. This is consistent with the previous research by Jones et al. (Jones, Connolly, Gear, & Read, 2006) who used a Likert survey while implementing the use of facilitated discussion and found both the students and lecturer felt greater student involvement enhanced learning and decision-making skills.

Attitudes from those students who received lecture had a more even distribution than those who received the hands-on DLM treatment. The number of students preferring lecture to DLM was 40% (strongly agree, agree), with 20% unsure of which pedagogy they prefer, and 40% who do not think lecture helped or would have helped more than the DLM (disagree, strongly disagree). The even split between student attitudes towards lecture indicates students were divided in their views about their experiences with lecture. It is somewhat difficult to draw concrete conclusions from these responses as there may be several reasons students did not have consensual attitudes towards either pedagogy. Perhaps students were not accustomed to the instructor's teaching style, perhaps they have a different learning style other than that favored or promoted by use of the pedagogy, or perhaps they did not enjoy the course material. The actual reason students are so split on the issue will remain unknown, but comparison between the two pedagogies and the corresponding student attitudes can offer insight into best classroom management and planning strategies in the future.

Comparing student attitudes and responses between lecture and the hands-on DLM can offer insights into their preferred experience. The survey response that has the most variation is strongly agree, where students prefer to have the hands-on DLM experience in lecture 21% of the responses. Additionally, the average responses, found by assigning rankings of 1 to 5 for strongly disagree to strongly agree, from the lecture experience moderately agreed that lecture helped with conceptual understanding with a value of 2.9/5 while the response for the hands-on DLM experience lies between agree and strongly agree, i.e. 3.9/5. In other words student attitudes gained a whole point on a five-point Likert scale in their considering the hands-on pedagogy as being more effective in helping them to understand and apply principles. The stronger preference towards the hands-on DLM experience suggests instructors should continue using the hands-on DLMs with base units and interchangeable cartridges in the future.

3.2 Conceptual Understanding

The second component of the Likert-survey questions asked students to identify how well they believed they could understand and apply heat transfer principles based on their experiences with hands-on DLM and lecture. No students in the course indicated they did not have some level of conceptual understanding regarding heat transfer concepts, as clearly indicated in Figure 6. Considering the implementation of the two pedagogies, this finding indicates that both are viewed as satisfactory for communicating conceptual information. However, this study aims to identify which pedagogy is preferred, and responses to this component of the survey can offer

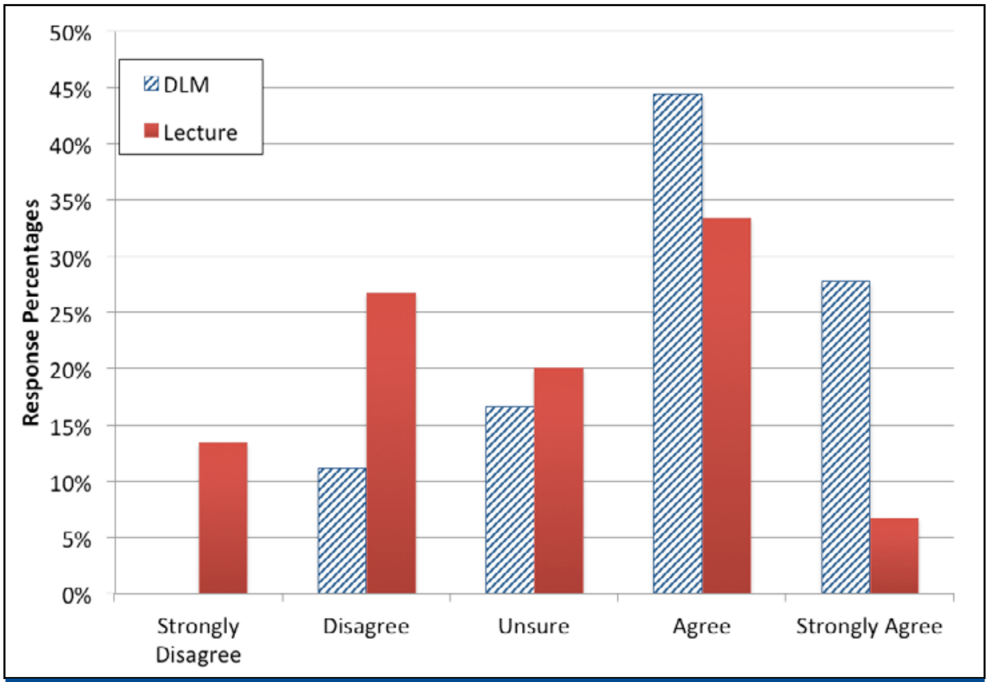


Figure 5: Summary of attitudinal survey responses. DLM: combined responses to "Hands-on group learning helped/would have helped more than lecture to understand and apply principles related to shell and tube heat exchangers (or evaporative cooling)"; Lecture: combined responses to "Lecture helped/would have helped more than hands-on group learning to understand and apply principles related to shell and tube heat exchangers (or evaporative cooling)".

insight to this question.

The hands-on DLM responses show student self-identified responses were split with 72% indicating they obtained conceptual understanding of the material (strongly agree, agree) and 28% unsure if they had mastered heat exchanger concepts. Students receiving lecture self-identified as having obtained conceptual understanding in 80% of their responses, with 20% of the students unsure of their own concept mastery. Considering the two pedagogies, not much difference exists between student self-identified conceptual understanding.

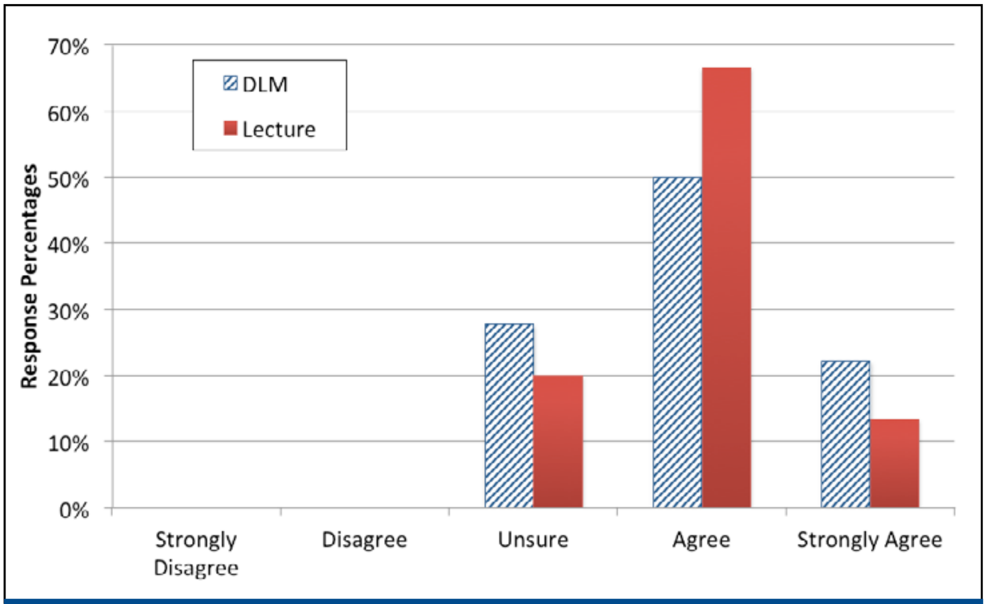


Figure 6: Combined responses to "How well do you believe you understand and can apply principles related to shell and tube heat exchangers (or evaporative cooling)?" indicating students perceived adequate conceptual understanding of both shell and tube and evaporative cooling concepts.

3.3 Implementation Feedback

To better understand and interpret the quantitative results from both student attitudes and their self-identified conceptual understanding, the free-response question that solicited suggestions on modifying the hands-on DLM experience gives rationale or justification as to why students develop certain attitudes towards each respective pedagogy and insights on how to improve the use of the DLMs. For example, a major theme that emerges is the desire for students to have a strong lecture component in the classroom, which was independently supported by one-third of the 31 students who offered textual responses. One student suggested, "use DLMs to supplement lecture . . . using the DLMs requires at minimum a simple understanding of the basic concept to know what to do with the data being taken." To further emphasize this point, one student noted, "I think it would be beneficial to have lecture so there is an overall understanding of what is going on before doing hands-on exercises, a third responded, "I believe that the hands-on learning is useless without a bit of lecture or previous reading." A fourth states, "Give all information, readings, equations, theory (related) to the DLM before doing DLM." These responses highlight that students desire lecture to give them a basic understanding of the material before encountering an implementation with the DLMs. We note this is in contrast to the fact that the preparatory quizzes were designed to give students this desired introduction, and worksheets designed to lead teams through an interactive guided inquiry to teach concepts. Even though in this setting professors and TAs circulate among teams to discern if persistent difficulties are present and then present mini-lectures at the end of each class period, student responses indicate a more thorough overview presentation of the concepts through a lecture before using the DLM would be helpful.

A corollary to this theme is a desire for the DLMs to always be complemented by significant lectures; students who have interacted with them believe they were not adequately prepared nor properly guided by the worksheets. For example, a student responded, "I don't think [the DLMs] can replace lecture at all. They can enhance learning after the lecture has been given, but I don't think they are stand-alone learning aids. Another student responded, "The most important thing to me in college has been my personal understanding and knowledge, not the grade. I have found that for me, the DLMs have the potential to be a very valuable teaching tool, but without a strong theoretical base from lecture they can simply be a waste of time." These students indicate they learn from the DLMs but would prefer them used as an addition to lecture, not as a replacement for lecture.

Students also highlight a strong feature of the DLMs is that they can help students contextualize what they are learning in the classroom by emphasizing the visual learning style characteristic to so many engineering students as reported in the theoretical framework section. This is supported by students statements such as: "Flow patterns, regime and equipment geometry are easily visualized through hands-on experiments, it would be much easier to understand/remember how these change through the DLMs," and "I was able to observe the shell and tube heat exchanger and the most useful part of the experiment was simply seeing the exchanger. The diagrams which were available in the required text were simply too inadequate to describe the geometry involved." However, using these visual skills when faced with equipment and the feeling of an inadequate foundation is difficult. Posner (2006) explains that learning is a rational activity that is composed of ideas and evidence, and it is important to ensure learners have a basis of ideas before encountering evidence to further those ideas. Bligh noted that lectures are not meant to promote thought or provide deep learning experiences, but that does not mean that lectures cannot offer a good foundational understanding of ideas before participation in a pedagogy that better contextualizes information (Bligh, 2000).

The qualitative results that differentiate between the student attitudes and self-identified conceptual understanding can also help inform the best use of DLMs in the classroom. Students clearly indicated a positive attitude from the hands-on DLM experience, supported by high survey responses from both student attitudes and conceptual understanding. However, the lack of a clear preference between DLM and lecture for conceptual understanding indicates that both pedagogies are perceived by students to communicate heat transfer concepts. Based on their responses, the preference would be to receive a lecture to offer a foundation and the DLMs as an aid to enhance learning, visualize the system, and contextualize information gleaned from lecture.

4 Recommendations and Conclusions

This study assessed student attitudes, self-identified student conceptual understanding and student suggestions for implementation of heat transfer hands-on desktop learning modules. The aim was to determine the preferred pedagogy between lecture and the hands-on DLMs for use in the classroom in terms of learning the principles governing heat transfer processes. Results from an attitudinal question on a five-point Likert-scale survey indicate students prefer the hands-on DLM pedagogy over lecture, however the second Likert-scale survey responses indicate no difference in self-identified student conceptual understanding between the two treatments. Text responses asking students for suggestions of how to improve the DLM experience indicate a desire for a lecture giving a foundation of heat transfer concepts before the hands-on DLM experience. Students expressed how the DLMs allowed them to contextualize the concepts but that without a guided lecture-based foundation it is not an optimal pedagogy. This finding is also supported by dual coding theory, where the DLMs can leverage the benefits of visual working memory and lecture for audio working memory.

Based on the implementation and assessment of the hands-on shell and tube and evaporative cooling DLM cartridges in a fluid mechanics and heat transfer classroom, the overwhelming student preference is to use the DLMs following a short lecture emphasizing theory, especially for those concepts which require special attention to spatial and geometric considerations.

Acknowledgements

The authors are grateful for support from NSF grants DUE 0618872, 1023121 and 1432674, the NSF grant CBET 0731230, and WSU Voiland College of Engineering and Architecture machinist Mr. Gary Held for construction and critical assistance with design of the DLM system.

References

Abdul, B., Brown, G. R., Thiessen, D., Golter, P. B., & Van Wie, B. J. (2010). *Bringing research into the classroom: Conceptually new heat-exchanger.* Paper presented at the American Society of Engineering Education, Louisville, KY.

Abdul, B., O'Rear, E., Brown, G. R., Kranov, A. M. A., Van Wie, B. J., Golter, P. B., & Thiessen, D. B. (2011). *Experience with a cross-disciplinary intensive, hands-on pre-transport course.* Paper presented at the ASEE Annual Conference and Exposition, Vancouver, BC.

Besterfield-Sacre, M., Atman, C. J., & Shuman, L. J. (1998). Engineering student attitudes assessment. *Journal of Engineering Education, 87*(2), 133-141.

Bligh, D. (2000). *What's the use of lectures?* San Fransisco: Jossey-Bass.

Burgher, J. K., Thiessen, D., & Van Wie, B. J. (2013). *Desktop learning modules for fluid mechanics and heat transfer* Pullman, WA: Washington State University.

Chandler, & Sweller. (1992). The split-attention effect as a factor in the design of instruction. *British Journal of Educational Psycology, 62*(2), 233-246.

Chickering, & Gamson. (1987). Seven principles for good practice in undergraduate education. *AAHE Bulletin, 39*(282), 3-7.

Clark, W. M., DiBiasio, D., & Dixon, A. G. (1998). *An integrated, project-based, sprial curriculum for the first year of chemical engineering.* Paper presented at the FIE, Tempe, AZ.

Coon, Golter, P. B., Cline, D. A., Kranov, A. M. A., Thiessen, D. B., & Van Wie, B. J. (2011). *Unit operations lab bazaar: Assessment of minature industrial equipment.* Paper presented at the American Society of Engineering Education, Vancouver, BC.

Educating the engineer of 2020; Adapting engineering education to the new century. (2005). Washington DC: National Academies Press.

Felder, & Silverman. (1988). Learning and teaching styles in engineering education. *Engineering Education, 78*(7), 674-681.

Fulton, K. P. (2012). 10 Reasons to flip. *Phi Delta Kappan, 94*(2), 20-24.

Golter, P. B., Van Wie, B. J., & Brown, G. R. (2007). *Comparing student experiences and growth in a cooperative, hands-on, active, problem-based learning environment to an active, problem-based environment.* Paper presented at the American Society of Engineering Education, Honolulu, HA.

Jones, Antonenko, P. D., & Greenwood, C. M. (2012). The impact of collaborative and individualized student response system strategies on learner motivation, metacognition, and knowledge transfer. *Journal of Computer Assisted Learning, 28*(5), 477-487.

Jones, Connolly, Gear, & Read. (2006). Collaborative learning with group interactive technology - A case study with postgraduate students. *Management Learning, 37*(3), 377-396.

Jones, & Issroff. (2005). Learning technologies: Affective and social issues in computer-supported collaborative learning. *Computers & Education, 44*(4), 395-408.

Jones, Kehle, & Bray. (2004). Computers in the delivery of special education and related services: Developing collaborative and individualized learning environments. *Psychology in the Schools, 41*(2), 275-277.

Lee, C. S., McNeill, N. J., Douglas, E. P., Koro-Lyungberg, M. E., & Therriault, D. J. (2013). Indispensable resource? A phenomenological study of textbook use in engineering problem solving. *JEE, 102*(2), 269-288.

Longo, S., Valiani, A., Lanza, L., & Liang, D. F. (2013). Experimental study of the grain-water mixture flow past a cylinder of different shapes. [Article]. *European Journal of Mechanics B-Fluids, 38*, 101-113.

Mayer. (2005). *Cognitive theory of multimedia learning*. New York: Cambridge University Press.

Mayer. (2009). *Multimedia learning (2nd Ed.)*. New York: Cambridge University Press.

Moreno, & Mayer. (2002b). Learning science in virtual reality multimedia environments: Role of methods and media. *Journal of Educational Psycology, 94*, 598-610.

Paivio. (1991). Dual coding theory: Retrospect and current status. *Canadian Journal of Psychology, 45*(3), 255-287.

Paivio, & Clark, J. M. (1991). Dual coding theory and education. *Educational Psycology Review, 3*(3), 149-170.

Posner, G. J. e. a. (2006). Accomodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211-227.

Prince, M. (2004). Does active learning work? A review of the research. *Journal of Engineering Education, 93*(3), 223-231.

Russian, C. (2005). Preferred learning styles for respiratory care students at Texas State University. *The Internet Journal of Allied Health Sciences and Practice, 3*(4), 1-6.

Simonson, S. R., & Shadle, S. E. (2013). Implementing process oriented guided inquiry learning (POGIL) in undergraduate biomechanics: Lessons learned by a novice. *Journal of STEM Education, 14*(1), 56-63.

Thomson, C., Brown, D., Jones, L., Walker, J., Moore, D. W., Anderson, A., & Glynn, T. L. (2003). Resource teachers learning and behavior: Collaborative problem solving to support inclusion. *Journal of Positive Behavior Interventions, 5*(2), 101-111.

Van Merriënboer, G., & Sweller, J. (2005). Cognitive load theory and complex learning: Recent developments and future directions. *Educational Psycology Review, 17*(2), 147-177.

Yadav, A., Shaver, G. M., & Meckl, P. (2010). Lessons learned: Implementing the case teaching method in a mechanical engineering course. *Journal of Engineering Education, 99*(1), 55-69.

Jacqueline K. Burgher is a PhD Candidate at Washington State University in the Chemical Engineering department. She received her bachelor's degree from Anderson University, worked in industry and earned an MBA from Anderson University. She is currently working with Prof. Bernard Van Wie on fabricating, optimizing, and implementing a miniaturized gasification system for use in the engineering classroom.

David M. Finkel graduated from Washington State University with a degree in Chemical Engineering in 2014. During his time there he worked with professor Bernard Van Wie evaluating hands on teaching pedagogies for chemical engineering students. Following graduation he began working as a process engineer for CH2M.

Olusola O. Adesope is an Associate Professor of Educational Psychology at Washington State University, Pullman. His research is at the intersection of educational psychology, learning sciences, and instructional design and technology. His recent research focuses on the cognitive and pedagogical underpinnings of learning with computer-based multimedia resources; knowledge representation through interactive concept maps; meta-analysis of empirical research; and investigation of instructional principles and assessments for engineering designs.

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 Washington State University faculty for 32 years and for the past 18 years has focused on innovative pedagogy research and technical research in biotechnology. His 2007-2008 Fulbright exchange to Nigeria set the stage for him to receive the Marian Smith Award given annually to the most innovative teacher at Washington State University.

Appendix

Contained in the appendix are the preparatory quizzes, and worksheet exercise prompts that accompanied the hands-on activities or formed the basis for a lecture, depending on which exposure a set of students was given, and homework exercises. We note the material is given in compressed format to conserve space for the publication.

Preparatory Quiz

Learning Objectives/Outcomes:

1. Identify how a Shell & Tube heat exchanger (S&T HtX) differs from a Double Pipe HtX
2. Understand how various design parameters affect performance
3. Understand the structure of a S&T HtX

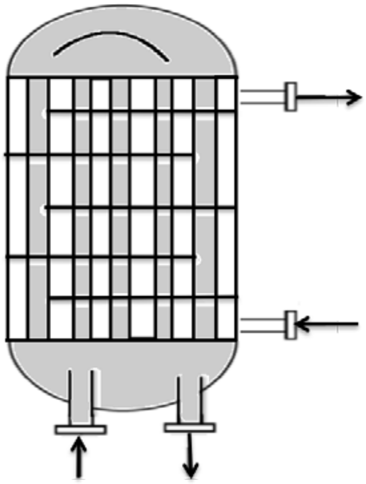
---

1. Why would one use a S&T over a double pipe?
2. Give short descriptions of how the following design decisions offer tradeoffs in terms of tube side pressure losses and heat transfer for given shell-side and tube-side flow rates.
   a. Increasing the number of tube passes (P_t)
   b. Increasing the number of tubes (N_t)
   c. Increasing the diameter of the tubes (D_t)
3. What is the purpose of using baffles in the shell of a S&T H_tX?
   a. How do the baffles affect the flow patterns in the shell relative to the tubes and how are those changes accounted for?
   b. How does one determine the shell side parallel and cross flow mass velocities if one knows the following: shell diameter, baffle window fraction, number of tubes, size of the tubes, tube pitch, and baffle pitch?
4. What is the heat transfer driving force in a S&T H_tX? How is it treated differently (i.e. corrected) as compared to a double pipe Ht-X? Why is this correction necessary?
5. Draw a shell and tube heat exchanger and draw a cross section of the tube pattern including the baffle window. Label the following: $T_{h,in}$ & $T_{h,out}$ (the best choice on the diagram), Shell inside diameter, D_s, Tube spacing, c', Tube OD, D_o, $T_{c,in}$ & $T_{c,out}$ (the best choice), Baffle window, B_w, Tube length, L, Baffle pitch, P_B, Tube pitch, P_t.

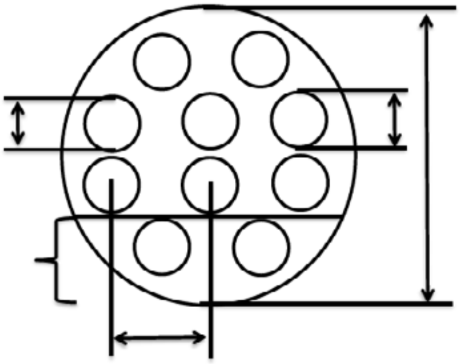
Worksheet & Homework

Relevant information about the DLM:
DLM Parameters:
Tube passes, n_p = ____
Shell passes, n_s = ____
Number of tubes, Nt = 10
Tubes per pass, n_t = 5
Tube length, L = 231 mm
Tube OD, Do = 6.35 mm
Tube ID, D_i = 5.15 mm
Tube pitch, P_t = 15.1 mm
Baffle pitch, P_b = 44.3 mm
Shell inside diameter, D_s = 47.0 mm
(see below for baffle layout)
Baffle window fraction, f_p = 0.22
Number of baffles, n_b = ____
K^{H20} = 0.58 W/mK
K^{Steel} = 16 W/mK
C_p^{H20} = 4186 J/kgK

The configuration of the Shell & Tube HtX is below:
Note: Tube fluid flows in shaded regions



Below is the tube layout and baffle window. Label the 5 dimensions on the schematic below.



Directions

If you begin with the DLM, please follow the experimental procedure (below) and start at question 4. If not, begin at question 1.

Experimental Procedure – Some of these steps may have already been done by your Professor/TA

1. Make sure both reservoirs are filled to the point where the float is at its maximum height
2. Attach the cartridge to the leftmost tank
3. Plug in the tubes from the shell into the appropriate valves on the second tank. The lower tube should attach to the closer valve.
4. Make sure Tank A (where the cartridge is attached) contains hot water (WHICH SHOULD NOT BE ABOVE 60°C) and tank B contains the cold water
5. Make sure both pump dials are turned completely counterclockwise (off)
6. Turn on both base units
7. Make sure all 4 temperature readings are displayed
8. Slowly increase the flow rates by rotating the dial clockwise until reaching ~100 GPH on both units
9. Wait ~1 minute, then record all 4 temperatures
10. Change the flow rate of TANK A ONLY to ~25 GPH and record values after ~1 minute. Turn off the pumps when not needed so that tank temperatures do not equilibrate
11. Carefully analyze the heat exchanger itself, and the supply and return streams and answer the worksheet questions
12. Turn in one DLM Worksheet per group
13. Complete the homework questions after class

Largest shell side flow (GPH):		**Largest tube side flow (GPH):**	
Supply B (Shell inlet) $T_{cold,in}$ (°C)	**Return B (Shell outlet); $T_{cold,out}$ (°C)**	**Supply A (Tube inlet) $T_{hot,in}$ (°C)**	**Return A (Tube outlet); $T_{hot,out}$ (°C)**
3 min:			
Largest shell side flow (GPH):		**Small tube side flow (GPH):**	
Supply B (Shell inlet) $T_{cold,in}$ (°C)	**Return B (Shell outlet); $T_{cold,out}$ (°C)**	**Supply A (Tube inlet) $T_{hot,in}$ (°C)**	**Return A (Tube outlet); $T_{hot,out}$ (°C)**
3 min:			

1. Consider the various temperatures $T_{h,supply}$, $T_{h,return}$,$T_{c,supply}$, & $T_{c,return}$.. Label them on the arrows in the diagram above. Note: the hot fluid goes into the *tubes*. Which combination should be used to do an *energy* balance on the shell side? How should they be used to complete a heat transfer *correlation*?
2. What are the two interfaces at which heat transfer occurs? Write formulas for them:
   A_o =________________
   A_i =________________
3. Draw in flow direction arrows of the shell fluid as it travels from entrance to exit. What is the purpose of putting baffles in the shell? How do they affect the behavior of the shell fluid? Do the shell baffles change the velocity of the shell fluid? What about the time the fluid spends in the shell (also referred to as residence time)?

4. U_o, the overall heat transfer coefficient based on the outside area can be expressed as follows:

$$U_o = \frac{1}{\frac{A_o}{A_i}\frac{1}{h_i} + \frac{A_o ln\left(\frac{R_o}{R_i}\right)}{2\pi L k^{wall}} + \frac{1}{h_o}}$$

a. If the tube side flow reduces to laminar flow, which resistance will be controlling? Why? Circle it above.

b. Examine your data acquired for the flow rate of ~25 GPH in the tube side. What do you notice about the ΔTs across the entrance and exit streams? Why has this happened?

5. What are parallel and cross flow, and at what points in the S&T would you find parallel flow and cross flow?

a. By visual inspection, determine formulas for the area available in cross flow in the center of the shell and parallel flow in the baffle window of the shell of the HtX, A_{cross} & $A_{parallel}$. See if they agree with the derivations in your textbook. Why do you use the center most row for the cross flow calculation?

6. What is the purpose of the log mean temperature difference correction factor, F_T? Visually follow the flow of the shell fluid and discuss at which points it is in contact with the warmest and coolest sections of the tube fluid. Briefly describe your conclusions and tell why you need the correction factor, F_T.

Homework

Shell Side Calculations

1. Calculate the areas for cross and parallel flow and use the flow rate of the water to determine the average mass velocity in the shell in lb/ft^2-hr. Note that 1 ft^3 = 7.48 gal, and that the density of water is 62.4 lb/ft^3. Discuss how the areas for cross and parallel flow would change when increasing the following (while holding everything else constant): a) the number of tubes; b) the diameter of the tubes; c) the number of tube passes; d) the number of shell baffles.
2. Use the average mass velocity to determine the shell side Reynolds number. Use an appropriate nomograph from a textbook to determine the viscosity of water and note that 1 cP = 2.42 lb/ft-h. Which diameter should be used in calculating the shell side Re number?
3. Determine the shell side Prandtl number. Now calculate the shell side Nusselt number and the shell side heat transfer coefficient, h_o, with the Donahue equation.

Tube Side Calculations

4. Use the tube side flow rate to calculate the mass velocity and tube side Reynolds number as above.
5. Choose an appropriate correlation to determine the tube side Nusselt number and heat transfer coefficient, h_i. Discuss how you chose this correlation.

Driving Force Calculations

6. Determine the log mean temperature difference from your recorded temperatures.
7. Determine the log mean temperature driving force correction factor using appropriate methods outlined in your textbook. Discuss the meaning of the parameters used to determine the correction factory.

Putting It All Together

8. Determine the outside or inside surface area of contact, A_o or A_i, for the Ht-X. Discuss how this area would change when increasing the following (while holding everything else constant): a) the number of tubes; b) the diameter of the tubes; c) the number of tube passes; d) the number of baffles.
9. Determine the overall heat transfer coefficient, U_o or U_i.
10. Combine all of this information to determined $Q_{correlation}$.
11. Do an energy balance on both fluids to determine $Q_{actual,avg}$. Calculate a percent error and discuss the discrepancies average $Q_{energy\ balance}$ and $Q_{correlation}$.

Discussion Questions

1. Consider how the number of tubes, number of turns, number of baffles, and diameter of tubes affect pressure drop, relevant heat transfer coefficients, and surface area of contact by thinking through the overall procedure followed above. Summarize key thoughts.
2. Why is the hot fluid often put on the tube side rather than the shell side? Is there any reason you may want to put a cold fluid in the tubes rather than the shell?
3. How do double pipe and S&T heat exchangers differ from one another? What must you do differently when solving a problem for each system?

II. Evaporator, Preparatory Quiz, Worksheet and Homework

Preparatory Quiz

Learning Objectives/Outcomes:

1. Understand the various driving forces behind evaporative cooling
2. Understand how these driving forces depend on ambient conditions
3. Understand the various structures of evaporative coolers

---

1. Imagine getting out of the shower before drying yourself. Why does the presence of water on your skin make you feel colder?
   a. How would this sensation change if the air were being blown across your body? Why?
   b. Which dimensionless number could be used to correlate the rate of mass transfer? Can you create an analogy to a dimensionless number used for energy transfer?
   c. How would evaporative cooling change if the air were more humid?
2. Explain what a wet bulb temperature is. Include both sensible and latent heat in your explanation.
   a. What does the wet bulb temperature tell you about the potential limit of an evaporative cooling system?
3. The driving force behind mass transfer is a concentration differential and the driving force behind heat transfer is a temperature differential.
   How are both of these driving forces accounted for in the wet bulb temperature? [Hint: use the definition of a wet bulb temperature.]

Worksheet and Homework

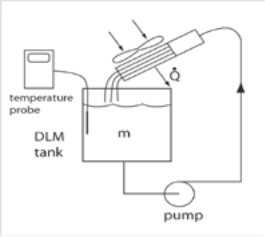
Water flow rate: ________ (GPH) Air speed ________ (m/s) A_x (air) ________(cm^2)

Time (min)	Tank temp (°C)
0	

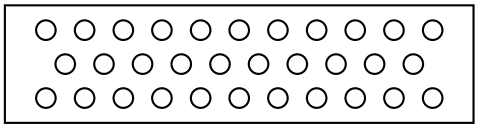
volume of water in tank _____ cm^3

wet bulb temperature _____ °C

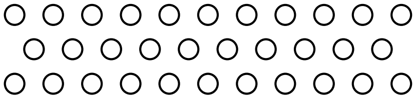
dry bulb temperature _____ °C



1. Find the average heat duty of the DLM evaporative cooler from the data in the table above over the initial five-minute period.
2. The fill material for the DLM cross-flow evaporator consists of parallel springs that form channels for water to flow down while a fan blows air across the channels. Water is distributed through 32 of these channels in parallel. The header layout is shown below. The center-to-center pitch is 0.25 inches and the channel OD is 0.125 inches.
    a. Estimate the parameter *a* (water surface area per volume of fill material) for the DLM evaporator. Assume that water surface area is 50% of the outside area of a cylinder with the same OD as the springs. Decide what is meant by volume of fill material.
    b. Explain how you will find Gx and Gy' for this evaporator from the geometric parameters and flow rates.



3. Perform the following exercises or answer the given questions.
    a. Draw streamlines on the diagram below to indicate the flow of air past the channels. Also indicate on the diagram where thermal and solute boundary layers would form.



    b. Make a list of suggested modifications to the DLM evaporator to enhance the heat duty and explain why each one would help.
    c. Assume you are trying to cool water that is at 100°F. Are there any ambient air conditions for which you would expect no change in the tank temperature while running the evaporator? If so, list these conditions and explain.
4. Calculate the predicted heat duty of the DLM evaporator using an appropriate correlation for the mass transfer coefficient and the enthalpy driving force and compare this to the experimental value determined in question 1. Use flow rates, inlet temperatures, and conditions recorded at the start of the worksheet and assume the following property values.

Physical property data

Air: $\rho = 1.18$ kg/m^3; $\mu = 1.84 \times 10^{-5}$ kg/m·s; $k = 0.026$ W/m·K; $D_w = 2.57 \times 10^{-5}$ m^2/s

H2O: $\rho = 998$ kg/m^3; $\mu = 1.00 \times 10^{-3}$ kg/m·s; $k = 0.597$ W/m·K; $\Delta H^{vap} = 2.44 \times 10^6$ J/kg