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Evaluation of the Effectiveness of Individual Hands-on Workshops in Heat Transfer Classes to Specific Student Learning Outcomes*

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Twelve hands-on workshops were assigned to one fifty-person lecture class of heat transfer, while a second class of the same size was given corresponding homework problems. Although everything else between the classes was maintained the same, the overall performance of the workshop class was previously shown to be significantly better than the non-workshop class. This was true including both concept questions and quantitative problem solutions. The current paper looks in detail at specific workshops that were helpful on the topics of transient conduction, energy balance with multiple conduction pathways and relative resistances, external convection, and gray body radiation. Student feedback on the workshops is used to help elucidate what worked for each workshop and what needs improvement. This includes suggestions for better workshops on fins and lumped capacitance based on what concept is most difficult for the students to grasp. Finally, a basis for evaluating this teaching method is established.

Keywords: thermal measurements; heat transfer concepts; hands-on workshops; heat flux

1. Background

Laboratories have always been considered an important part of engineering education. Recently, however, the best format for doing this hands-on component of student education is being questioned. This particularly came to the forefront because of the COVID-19 shutdown of traditional classrooms and laboratories. Traditional labs are notoriously expensive in terms of equipment costs and dedicated space. Moreover, as engineering enrollments continue to increase, it is often difficult for large schools to schedule student access throughout the week. This results in either larger groups of students using any single piece of equipment or limited time for students to complete the tasks assigned. The three-hour lab has now become a two-hour lab with resulting rush just to complete it. This leaves little time for student discovery, which is considered vital for student learning. Labs that go beyond the "cookbook approach" are difficult to design and even more difficult to run efficiently.

Different types of laboratories have been tried in science and engineering classes, with a variety of results [1, 2]. The most common replacement of traditional in-person labs have either been virtual or remote. In one case videos of the dynamics of body motion were shown to students [3]. In another case, a combination of in-person and virtual (video) labs were found to be better than either alone [4]. Software-based simulations of the lab were developed that allow students to interact with the simulation [5, 6]. A real-time video of the lab that is performed by a technician [7] is another option that was particularly useful during COVID-19. A link from student computers to the experimental controls with a video of the results allows more feedback [8]. One step further (SCALE-UP) is to have the students perform the experiments in teams with one student doing the experiment in the laboratory room while the remaining students interact with each other via a real-time web link [9]. Often laboratories are assumed to teach only techniques rather than as practical training of engineering design and analysis. Assessment of the educational impact is rarely done or is based only on student perceptions [10].

A more recent approach has been to connect hands-on learning directly as part of the corresponding lecture course. This has most often been done for electronics courses or physics courses either during class time [11–13] or the students are individually given an inexpensive set of instruments and a bread-board to perform electronic experiments themselves [14].

The integration of hands-on activities into courses has shown significant learning gains for students in chemical and mechanical engineering also. Simple desktop modules have been introduced into the classroom to demonstrate fluid mechanics and heat transfer concepts through interactive learning in small groups [15, 16]. A large study of chemical engineering students was performed to determine the value of hands-on versus virtual learning activities [17]. They focused on one experi-

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ment with a double pipe heat exchanger for heat transfer and a hydraulic loss module for fluid mechanics. They found small increases in subsequent question performance for the heat transfer after pre-test and post-test, which was statistically the same for hands-on relative to the virtual. They did not answer the question of the value of either intervention versus the usual lecture format, however. This is the most important question – whether either intervention is useful relative to a control class. In addition, the hands-on experiment was done in groups of 2 to 4 students in which one student typically does the hands-on work while the others watch. This lowers the learning experience for most of the students. The fluids experiment showed a much larger positive effect, which was attributed to the more visual nature of fluid mechanics. Conversely, heat transfer is not easily visualized nor was it measured. Instead, it was inferred from a series of calculations. Similar results were found for a fluids experiment [18] and light bulb in a box heat transfer experiment [19].

The method of measurement and data acquisition is another aspect that is often not explored as an important factor. Bernhard [20] used three different methods to measure the position, velocity and acceleration of a cart on an incline. Computer data acquisition gave the students much more information to understand the phenomena they were studying, even though the data collection was more automated. This gave the students more insight. It is a challenge to design the lab for carefully guided study rather than as a cookbook exercise [21].

Hands-on workshops were used as part of a heat and mass transfer lecture course at Virginia Tech [22]. Students worked in teams of two in a specially equipped room to measure heat flux and temperature for the challenge-based workshops. The workshop challenges were focused on student conceptual learning while performing realistic heat flux measurements. There was a statistically significant effect on their conceptual understanding of flow and radiation that persisted to the end of the course. Performing the workshops was very time and resource intensive for the instructors, however. The effect disappeared the next year when the students didn't actually do the measurements themselves.

Hands-on learning has been added to a variety of courses in engineering. This can be with separate in-person labs, virtual labs done with video, experiments brought into lecture classes, or a combination of these. A number of papers have shown an improvement in learning concepts based on pre-test and post-tests gains, but the focus has generally been correcting misconceptions [23] Usually control groups in standard classes are not used and the number of students in the test is often limited to one relatively small class. Although improving engineering concepts is an important goal of education, better tests scores for these interventions should also be expected to make all of this effort worthwhile.

The current approach to hands-on learning is for students to perform exercises that combine measurements of heat flux and temperature to experience heat transfer at home. Each student has their own data acquisition system and sensors to investigate the world around them. The exercises are organized as workshops that guide them through the measurements and interpretation if results. This includes manipulation of equations to model real world situations and calculate answers to compare with the measurements. Details of the resulting performance in the course was compared with a comparable student group without the workshops. The purpose is to prove if this change in how heat transfer is taught would lead to improved performance and student engagement in the course.

2. The Heat Transfer Personal Engineering Platform (PEP)

In response to the challenges of hands-on education in heat transfer classes, a new approach was developed and tried in 2017 at Virginia Tech. Instead of bringing students to the experimental equipment in a laboratory or classroom at the University, the equipment was designed to be given to each student to take home [24]. This has been named the Personal Engineering Platform (PEP). A total of fourteen labs were designed as learning workshops and published on-line for free use [25]. This gives an opportunity for one workshop per week in a standard semester course. The reported results in 2022 showed that the class with the PEP workshops had better overall test and class performance than the class without. Ten years of data with the same instructor with back-to-back sections is shown in Table 1 with the number of students (No.), the average grade for each section (Ave.) and the p value comparing the two sections each year. Only in years 2017, 2018, and 2022 was there a substantial difference in scores between classes ($p < 0.05$). These were the years with a difference in PEP Workshops between classes. In the other years the p values were all greater than 0.1, although there was in most years better performance from the section at 10 than the section at 9. In all cases the student selection and assignment of sections was random with no difference in sections advertised to the students. This makes the better performance of the section at 9 even more remarkable in 2022.

Table 1. Average Score by Year and Section from 2013 to 2022 for sections at 9 and 10

Year	No. 9	No. 10	Ave. 9	Ave. 10	p value
2013	56	66	77	78.7	0.375
2014	58	64	78.8	79.7	0.647
2015	58	63	74.3	75.6	0.516
2016	62	64	78.2	77	0.580
2017	59	67	76.3	81.5	**0.014**
2018	70	71	78.05	82.9	**0.004**
2019	59	65	77	80.45	0.109
2020	67	67	80.1	80.3	0.916
2021	46	51	80.3	80.6	0.894
2022	54	59	76.5	71.5	**0.023**

The performance of the PEP section in 2017 was also better when the PEP class section was reversed from 9 to 10. The purpose of the present paper is to now take a deeper look to understand why and what specifically seemed to be the cause. Data was recorded for every test and quiz question in 2022 to allow detailed analysis of the effect of each workshop on specific topics being tested.

2.1 The PEP System

The key for a beginning heat transfer class is for the students to understand the meaning of heat flux (heat transfer per area). Conversely, everyone has a good feel for temperature. So, the most important component of the PEP system is a heat flux sensor. Heat flux sensors typically measure differential temperature with thermocouple arrays that produce microvolt signals. Consequently, the PEP system uses a specialized electronic board that is added to the usual microprocessor (e.g., Texas Instruments MSP432 or Arduino) to measure the microvolt signals from the heat flux sensor and thermocouples. This booster pack is designed around a zero-drift 24-bit A to D chip to give microvolt readings for low sampling rates (about 1 hertz). It also has a diode to measure the junction temperature of the thermocouples, which along with a built-in equation for T-type thermocouples gives absolute temperature values. The sensors and components of the heat transfer PEP kit are shown in Fig. 1. Included is a heat flux sensor with a thermocouple, a second separate thermocouple, a DAQ with a USB cable for computer connection, an aluminum coupon, a thin aluminum fin, a small piece of wood, a thin electric heater (0.23 mm thick) and a small piece of cloth. The heater is designed to take power either from the DAQ or from a separate battery pack. It is used to provide a source of heat for some of the workshops. Many of the workshops use the human body as a heat source, which allows students to feel the thermal process while measuring the results. The heater pattern is shown in Fig. 2 and

Fig. 1. Components of the PEP Heat Transfer System.

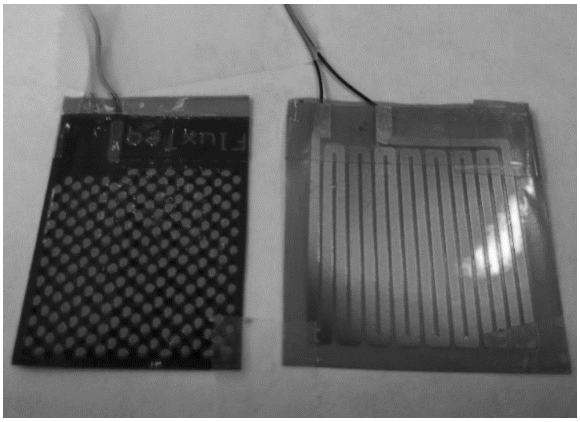


Fig. 2. PEP Heat Flux Sensor and Heater.

gives a nearly uniform heat flux of up to 1,000 W/m^2. The differential thermopile pattern of the heat flux sensor is also shown in Fig. 2. It is composed of many thermocouple junctions across a thin sheet of Kapton with a Kapton sheet covering each side. The entire sensor is about 0.38 mm thick. It outputs a voltage (E), which is directly proportional to the heat flux (q'') according to a supplied calibration (S), typically given as microvolts per watt per square meter, $q'' = E/S$. The computer program automatically does this conversion when supplied with the calibration value.

2.2 PEP Workshops and Evaluation Methods

Most of the workshops have two sheets for the students. The first is informational background on the situation and modeling considerations. The goal is to make the workshop self-explanatory with no additional instruction required. The second organizes the answers with diagrams, graphs and both numeric and qualitative answers. Probing questions are used to guide the students into thinking about the mechanisms and reasons for the observed behavior of the system. Since the workshop took the place of a usual homework problem, the material was meant to teach not only concepts, but also solution techniques that would be useful on test problems.

To help evaluate the effect of the workshops, detailed scoring of all of the quizzes and tests was recorded for two of the 2022 sections of heat and mass transfer. This was used to elucidate the specific impact of the individual workshops on the student performance in the course. The two sections were taught by the same professor at back-to-back times in the same room using the same quiz and test questions. The 9:00 class used the PEP workshops in place of one homework problem on the same topic as the workshop. The 10:00 class did only standard homework problems from the textbook as the Control section. Otherwise the lectures were done identically with the same format as used in each of the previous ten years. The student scores on each of the individual questions on the quizzes and tests were compared between the two sections to determine if there was a significant difference according the standard p test. This was based on the averages and standard deviations of the scores from the two sections. The workshops were then grouped into the following three categories. Each will be discussed in detail sequentially in the Results section.

Workshops with a Positive Effect
W5 Transient Semi-Infinite
W6 Heater on different materials
W7 Feeling materials with added cloth for fouling
W8 and W9 Convection
W13 Gray Body Radiation

Workshops with No Direct Effect
W3 Fins
W4 LCM
W11 Evaporation

Workshop Topics that were Not Directly Tested
W1 Introduction
W2 Metabolism
W10 Glass Window Conduction
W12 Building Heat Transfer Coefficients
W14 Make your own problem

3. Graded Results

Not all of the fourteen workshops were used and evaluated during in the 2022 heat transfer classes. Six of the workshops showed a clear improvement in student performance on concept questions and/or workout problems. Three of them did not show a statistically significant effect. A short description of each of these workshops is followed by the statistics on the specific questions used for evaluation.

3.1 Workshops with Positive Effects

Workshop 5 – Transient Semi-infinite
In workshop 5 the students generated plots of heat flux and temperature while placing their hands on high and low conductivity materials, in this case carpet and concrete. The temperature; response is about the same, but the heat flux is much higher with the high conductivity material, which is why it feels cold to the touch. Fig. 3 shows a typical example of the heat flux. Because the students only have one heat flux and temperature sensor combination, they have to repeat the test for each sample, which is why the time axis is slightly different for the two cases.

Students were tested on *Test 1 (Problem 1)* soon after this workshop was performed. The problem is shown below, with the answers marked in red. The Workshop section scored 88% compared to the Control section of 77%. The resulting p value was 0.004, which is quite significant. Each of the subsections had a significant p value also except for the

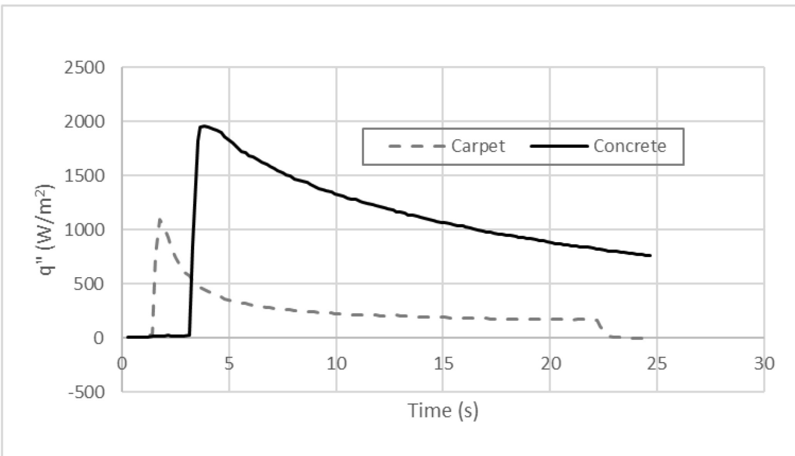


Fig. 3. Sample Heat Flux Plots from Workshop 5.

question 1.3. Both sections did well on this multiple-choice question. The 9 section still did better, but not with a significant p value.

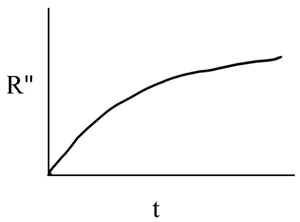
Test 1, Problem 1 For heat transfer into a semi-infinite material with a uniform initial temperature T_i with a sudden increase in the surface temperature T_o the penetration depth δ and surface heat flux q'' are

$$\delta = 4\sqrt{\alpha t} \quad and \quad q'' = \frac{\sqrt{k\rho C}}{\sqrt{\pi t}} \; (T_o - T_i)$$

1.1 Sketch the thermal resistance R'' in the material as a function of time for this process.

1.2 Indicate how the thermal resistance and surface heat flux are affected by increasing the thermal conductivity or specific heat of the material, (Increase (I), Decrease (D), or remains the same (S)) with all other factors the same.

	R''	q''
Increase thermal conductivity, k	*D*	*I*
Increase specific heat, C	*D*	*I*



1.3 When you touch a piece of metal and a piece of low density plastic at room temperature, the metal feels colder than the plastic. Choose the best reason to explain this:

a) The metal stores less energy than the plastic.
b) The metal changes temperature faster.
c) The heat transfer to the metal is higher.
d) The heat transfer to the plastic is higher.
e) The thermal contact resistance is higher for the metal than the plastic.

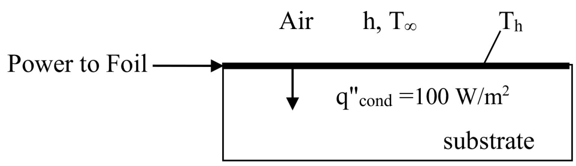
Workshop 6 – Heater on Different Materials

Workshop 6 uses the heater with a different heat sink on either side, as illustrated from the workshop in Fig. 4. On one side is a low conductivity material and on the other is a high conductivity material, like the aluminum piece. The heat flux sensor is alternately placed on either side of the heater to measure the transient heat flux in each direction To analyze the system requires the use of the energy balance with two separate pathways with very different thermal resistances. Understanding multiple thermal pathways is an important conceptual problem in many thermal systems.

The energy balance is used to show that the total power from the heater P has to go to the combination of the two materials. The students draw the overall energy balance on the figure and write the algebraic energy balance here in terms of the heat transfer to the high conductivity material q_{hc} and to the low conductivity material q_{lc}. Using the metal in the kit and a low conductivity material such as carpet, the heat flux is about six times higher to the high conductivity material.

Workshop 6 was assigned to the students in the latter part of the course to assist in understanding the thermal resistances in heat exchangers. It did not show an effect on heat exchanger problems, but did affect the student retention of key energy balance ideas. At the beginning of the course, a simple energy balance question was included on the first quiz to differentiate the initial concepts of the students. The Control class (10:00) did slightly better than the Workshop class (9:00), but not significantly ($p = 0.5$). Following the spring course, a quiz question on the energy balance was given to the students at the end of the fall semester (six months later) in a follow-on course, as shown below, *Fall 2022 Energy Balance Question*. Here the workshop class did much better (46% score) than the non-workshop class (30% score). Although the p value was only 0.10 for this direct comparison, when the previous two years of students with the same professor using Workshop 6 were included, the p value was 0.006. This provided a basis of 245 students who had done the workshop and scored an average of 50%.

Fall 2022 Energy Balance Question
A thin metal foil heater that is 0.1m by 0.1m in size is mounted on a substrate surface. The outer surface of the heater is exposed to air at a temperature of T_∞ = 20°C with a heat transfer coefficient of h = 10 W/m^2-K. If the foil is supplied with 5 W of electrical power and the conduction heat flux from the heater to the substrate is 100 W/m^2, what is the steady-state heater temperature, T_h? Assume one-dimensional transfer and neglect radiation.



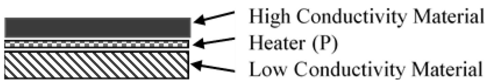


Fig. 4. Schematic of the System Used in Workshop 6.

Workshop 7 – Relative Resistance of Cloth

Workshop 7 is couched in terms of the insulative properties of walls or ceilings in buildings. In metal buildings insulation is often installed between the metal studs and the outer metal sheathing of the

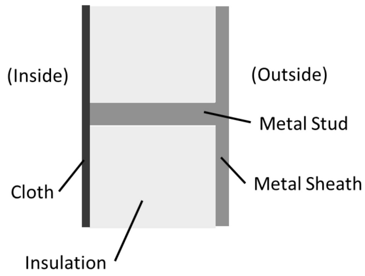


Fig. 5. Diagram from Workshop 7.

building. Consequently, there are two parallel pathways for the heat transfer – through the insulation and through the high conductivity metal studs. In addition, a layer of cloth is sometimes installed over the studs and insulation as shown in Fig. 5.

Some people argue that the cloth has no effect on the overall heat transfer because it is so thin. Others claim it is important because of the metal stud providing a thermal shunt through the wall. Students are tasked with making some simple measurements to prove or disprove this argument by inserting a piece of cloth over a piece of metal from the kit and then over insulation (for example carpet or a mattress). Students use their hand as a heat source with the heat flux sensor to measure the heat flux over 20 or 30 seconds for each of the four combinations:

(a) sensor directly on the metal piece from your kit.
(b) cloth between the sensor and the metal piece.
(c) sensor directly on the insulation.
(d) cloth between the sensor and the insulation.

The students should see no measurable difference in heat flux when placing the cloth on the insulation, but nearly a factor of two difference when the cloth is placed on the metal. The lesson is that even a small additional insulation is important when the thermal resistance of the system is small. This is an important concept when designing and optimizing thermal systems, including heat exchangers with fouling resistance. Most notably is that while the students are measuring the heat flux from their hand, they are also feeling the difference. This was related to the effects of fouling in heat exchangers on *Quiz 10* soon after Workshop 7 was performed. The items (b) and (c), as shown below, both had significantly better performance by the Workshop section versus the Control section. The average scores were 98% and 89% with a p value of 0.055 for item (b). For item (c) the scores were 85% and 62% with a p value of 0.007.

Quiz 10
The problem starts with a given heat exchanger with an overall heat transfer coefficient of U = *5,000* W/m^2*-K.*

(b) After operating for several months, fouling develops on the surfaces. Its effect on the actual heat transfer q is to INCREASE ***DECREASE*** *NO EFFECT*

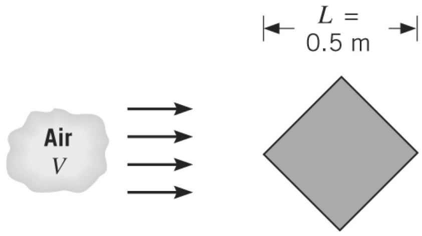
(c) If the value of the fouling factor was $R_f'' = 10^{-4}$ m^2*-K/W, will it have an important effect (> 10%)?*

YES *NO*

(The fouling factor will increase thermal resistance by more than 30%)

Workshop 8 – External Convection
Workshop 8 starts the study of convection by having the students place the heat flux sensor on their wrist and measuring the heat flux and temperature to find the corresponding heat transfer coefficient. First they make measurements in still air and then they rotate their arm to maximize the velocity and heat transfer coefficient. Based on a simple correlation for the Nusselt number as a function of Reynolds number they estimate the velocity that they achieved. This helps them to cement the Reynolds number as a non-dimensional velocity and the Nusselt number as a non-dimensional heat transfer coefficient with the same characteristic length used in both. These are very helpful concepts that are tested on the convection quizzes.

Quiz 5
(a) Experimental measurements of the convection heat transfer coefficient for a square bar in cross flow yielded the following value of average heat transfer coefficient: $h_2 = 150\ W/m^2\text{-}K$



Assume constant fluid properties.

It is desired to double the average heat flux from the bar while maintaining similarity. The fluid and surface temperatures remain the same. What size bar and change in fluid velocity is required?

L_2 = ***0.25 m***
V_2/V_1 = **2**

(b) If $Nu = a\sqrt{Re}$ *with flow past an object, how does the heat transfer coefficient change if the velocity is doubled with the same size object,*

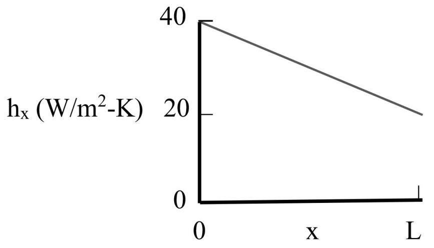
$h_2/h_1 = \sqrt{2}$

Is similarity maintained in this situation?

YES ***NO*** *Can't be determined*

(c) The local heat transfer coefficient on the surface

of an object is shown below. Estimate the corresponding average heat transfer coefficient,



(h_{av} = 30 W/m²-K)

The overall score for *Quiz 5* was 82% for the class section with Workshop 8 and 74% for the Control section with a p value of 0.07. The differences are more significant for the second (b) and third (c) parts of the quiz. The p values were less than 0.025 with scores of 78% and 64% for part (b) and 80% and 59% for part (c). Apparently, the relation of the heat transfer coefficient and Nusselt and Reynolds numbers to real world activities has a substantial impact on the students.

Workshop 9 – External Convection Jets

Workshop 9 has a similar theme as Workshop 8. Here the students tape the heat flux sensor to the piece of aluminum from their kits and blow on the sensor to create a heat flux event. From the temperature of their breath and the measured heat flux, a heat transfer coefficient can be calculated. Using a simple Nusselt/Reynolds relationship, a jet air velocity can be calculated and related to the lung pressure. Theses concepts were tested on *Quiz 6* and *Quiz 7*.

Quiz 6

A general form for the local heat transfer coefficient h_x for flow of velocity V in the x direction over a flat plate in non-dimensional form is

$$Nu_x = C\ Re_x^m\ Pr^n$$

where C, m, and n are non-dimensional constants. The coefficients m and n have values between zero and one. Assume the fluid properties k, ρ, Pr, ν, and C_p are constant and known.

(a) How does the local heat transfer coefficient h_x depend on x? ***($h_x \sim x^{m-1}$)***

Quiz 6 had the advantage of both Workshop 8 and 9. This seemed to have a substantial impact on the first part of the quiz. The workshop class had an average of 73% compared to the Control class average of 60% with p = 0.04. The remainder of the quiz dealt with integration of the local heat transfer coefficient to obtain the average over a surface. This is mostly mathematical manipulation and showed no effect of the workshops. The Control section without the workshops actually had a slightly higher average.

Quiz 7

Quiz 7 was the first quiz on internal flow. There were several parts to the quiz, but the only significant difference between sections was for part

(c) Determine if the flow is laminar or turbulent. ***(laminar with a calculated Reynolds no. = 637)***

The Workshop section scored 93% versus 79% for the Control section with a p value of 0.04. Although there are no workshops that deal directly with internal flow, the Reynolds number emphasis of Workshops 8 and 9 seemed to have a carry-over effect from external to internal flow.

Workshop 13 – Radiation

Workshop 13 has a focus on thermal radiation and the effect of surface emissivity. It uses a thick metal plate about 10 cm square with an electric resistance heater and an external power supply large enough to give at least 10 W of power. One-half of the plate is painted with a high-emissivity black paint and the other half is polished metal. The heat flux sensor is mounted onto the small aluminum plate in the kit to act as a heat sink. The large plate is heated to about 90°C, which is sufficient to easily feel the heat flux emitted and the difference between the black portion of the surface and the polished metal. The heat flux sensor is held close to the surface (but not touching) to directly measure the radiation exchange (typically about 400 W/m²). With some simplifying assumptions the emissivity of the polished metal can then be determined. But most importantly, the students can actually feel the effect of surface emissivity – the painted black surface will feel hotter than the bare metal surface, even though they are at the same temperature.

Final Exam and Fall 2022 Quiz

A person walks toward one of two diffuse grey surfaces that are maintained at 1000K.

Surface 1 has an emissivity of 0.50 and a reflectivity of 0.50

Surface 2 has an emissivity of 0.90 and a reflectivity of 0.10

Which statement is true?

a. The person will feel warmer as they approach surface 1 than surface 2.

b. The person will feel warmer as they approach surface 2 than surface 1.

c. The person will feel the same warmth in both cases.

d. Not enough information is given.

The class section with Workshop 13 scored 78% versus 42% for the Control section on this final exam question (p = 0.0001). The scores six months later in the fall of 2022 were similar at 77% and 49% (p = 0.005). This shows not only the immediate benefit of the workshop, but also a lasting change in conception. Workshop 13 left a strong impression on the students to believe the effect of surface emissivity on the perceived temperature of the surface and the resulting heat flux.

3.2 Graded Results for Workshops with No Effects

Workshop 3 – Fins

The fin workshop uses a thin piece of aluminum bent into an "L" shape with the smaller base mounted onto the top of the heater and the heat flux sensor as shown in Fig. 6. The wood block can be used to hold it in place and minimize the heat loss. The heat flux gage allows direct measurement of the heat transfer by conduction into the base of the fin, which is equal to the air cooling over the fin. The figure shows the arrangement as displayed in the Workshop 3 description.

Students were given an assumed heat transfer coefficient to calculate the fin efficiency from the measured heat flux and temperatures. This was compared with the analytical solution for a straight fin. Most students, however, did not understand how to then iterate their values of heat transfer coefficient to get the measured and analytical values to match.

Even though students were asked to feel the fin and estimate the distribution of temperature, this did not sufficiently relate to the fin efficiency. This was observed by no statistically significant effect of the workshop on three subsequent questions on a quiz, a test, and the final exam. This is consistent with other observations with the workshops that analytical solutions are not learned from the workshops. The focus needs to be on more basic concepts. Consequently, Workshop 3 was modified to eliminate the theoretical solution and focus on the concept of the fin efficiency. The students are now instructed to use their plot of the estimated temperature to directly calculate the fin efficiency and use that with the measured value of heat transfer to directly calculate the corresponding heat transfer coefficient. This is more straight forward and focuses on the meaning of the fin efficiency. This will now be tested in future course offerings.

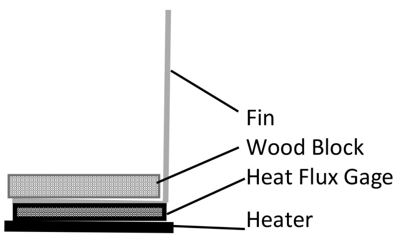


Fig. 6. Diagram of Fin System from Workshop 3.

Workshop 4 – Lumped Capacitance Model

Workshop 4 uses the aluminum piece in the kit with the heat flux sensor and thermocouples to illustrate transient heat flux and temperature. Several variations have been used over the past number of years to give the students a good experience, but they have all been based on using the body as a heat source. The current version is to wrap the aluminum in the cloth provided and then place it between the hands. This is the simplest type of lumped capacitance problem, however. The test problems often have a heat source, such as a heater that changes the steady-state temperature of the plate. Consequently, there was no statistically significant effect of Workshop 4 as measured on a quiz, a test problem and a problem on the final exam.

Consequently, an additional workshop is now suggested to address this issue. It is proposed to use the heater with the aluminum piece. First, the heat flux into the aluminum piece is measured, which will be close to a constant value. Then, heat flux to a heat sink with different amounts of thermal resistance will be measured, along with the temperature of the aluminum piece. The temperature and heat flux to the heat sink will be exponential, but with different time constants and the final temperature that is reached will also be different. The larger thermal resistance will give a larger final temperature and a larger time constant. Measuring and analyzing this transient system should give students added insight into lumped capacitance problems.

Workshop 11 – Evaporation

Workshop 11 measures the heat transfer from both the skin when it is dry and when it is covered with a wet cloth. The Lewis analogy is used to relate the heat transfer and mass transfer. The total transfer is much higher when wet, even though the temperature difference is nearly zero. Although this is an important concept for the students to experience, it did not have an effect on their problem performance. The scores on the mass transfer test problem on the second test were identically 80% for the Workshop and the Control sections. There are a lot of separate calculations to perform on these problems and the 80% score is good for both sections. Consequently, no changes are envisioned for this workshop.

4. Results of Student Evaluations

At the end of the course the students were given a number of questions as part of the course evaluation. Table 2 lists learning objectives for the course with the student perceptions of their ability to analyze these types of problems. All of the average values are between "Good" and "Excellent" with only a few students below this range. This is typical

Table 2. Student Perceptions of Ability to Analyze Heat Transfer Learning Objectives

Learning Objective	9:00 Class (Workshops)	10:00 Class (Control)
Energy Balances	3.6	3.48
Parallel/Series Pathways	3.47	3.26
Conduction with Internal Generation	3.4	3.33
Finite-Difference Conduction	3.28	3.15
Transient Effects	3.28	3.22
External/Internal Convection	3.55	3.33
Heat Exchanger LMTD and NTU	3.59	3.41
Total	3.45	3.31

Scale: 1-Poor, 2-Fair, 3-Good, 4-Excellent.

Table 3. Overall Course Evaluation

Evaluation questions at the end of the course.	9:00 Class (Workshops)	10:00 Class (Control)
1. I have a deeper understanding of the subject matter.	5.7	5.44
2. My interest in the subject matter was stimulated.	5.45	5.16
3. Overall, the instructor's teaching was effective.	5.65	5.27
4. I improved my ability to problem solve.	5.45	5.27

Scale: 1-Strongly disagree, 2- Disagree, 3-Somewhat Disagree, 4-Somewhat Agree, 5-Agree, 6-Strongly Agree.

Table 4. Student Ranking of the "Best" Workshop

No.	Topic	Top Ranking	Heat Transfer Objective
2	Body metabolism	4%	Relate heat flux to prior knowledge of caloric intake.
3	Heat transfer in fins	6%	Temperature distribution in a fin and fin efficiency.
4	Transient lumped capacitance	4%	Relate the exponential change in heat flux and temperature.
5	Transient thermal resistance	4%	Feel and measure transient heat flux and temperature.
6	Heat sinks and energy balances	2%	The importance of heat sinks on heat flux.
7	Relative resistance of cloth	4%	Limiting resistances for thermal system design.
8	Fluid convection	6%	How to measure heat transfer coefficients.
9	Jet impingement external convection	2%	Use forced convection correlations to estimate air velocity.
10	Glass window conduction	18%	Conduction and Convection steady-state energy balance.
11	Evaporation	10%	Relation of mass transfer to heat transfer.
13	Gray body radiation	8%	Measure and feel the effects of different emissivities.
14	Make your own problem	22%	Practice creative design.
All		10%	

of this course with this professor for the last ten years. Although all of these perception values are higher for the Workshop section relative to the Control section, all of the p values are greater than 0.75, with no statistical difference between sections. Clearly the student confidence in their abilities was not affected even though their actual performance was.

There are four standard questions on all of the student evaluations at the end of the courses at Virginia Tech. The students rank them from "strongly disagree" to "strongly agree". The average results are listed in Table 3. The average scores are all between "agree" and "strongly agree", which is again consistent with the past ten years for this course and professor combination. Although the Workshop section again has higher values for the course and the instructor, the difference is not statistically significant ($p > 0.7$).

Students were also asked which workshop they liked the best. The results are shown in Table 4. The first workshop was not included because it was just the introduction. The favorite was Workshop 14 where the students were encouraged to create and do a novel workshop of their own. There were many different ideas tried, some of which were quite innovative. Ten percent of the students indicated that they liked all of the workshops.

When the students were asked what they liked best about doing the workshops, they indicated the following distribution of word ideas.

Table 5. Most Liked Aspects of the Workshops

Idea	Fraction
Real Life	33%
Better Understanding	27%
Visualize	19%
Fun	8%

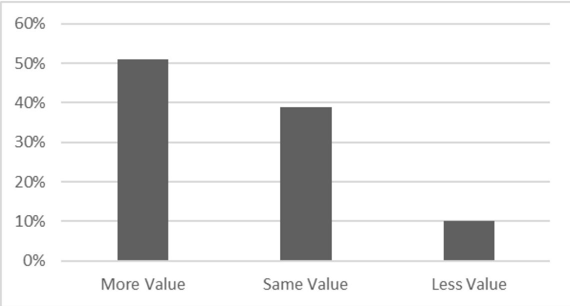


Fig. 7. Student Evaluation of the Workshop Value in 2022.

The least liked aspect of the workshops was associated with a software issue with the interface between the DAQ system and MatLab, which caused the system to occasionally freeze and required rebooting. This has since been fixed.

When queried about the value of the workshops relative to a standard homework problem, a majority of the students thought that the workshops were more valuable. Only 10 percent thought they were less important, as illustrated in Fig. 7. From conversations with some of these students, they were typically focused only on memorizing problem solutions in their attempt to pass the course.

5. Conclusions

A series of twelve hands-on workshops were used as part of a heat and mass transfer course in 2022 at Virginia Tech. Students performed the workshops individually as homework problems using the PEP kits that they were given for the semester. Comparison with a control class showed that five of the workshops had a direct impact on problem performance on tests and quizzes. Three of the workshops, however, did not have an anticipated improvement in performance relative to the control class section. Recommendations were made to improve two of these workshops for future classes. An additional five workshops were not directly tested. Overall, the workshops provided students the experience of measuring heat flux in realistic situations that reinforced basic concepts of the course. Their performance on conceptual questions and worked-out problems improved relative to the control class.

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