# The Role of Experiments in Inductive Learning

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## ABSTRACT

This paper presents the results of Rowan University chemical engineering department's efforts in teaching using the inductive method.  In this paper our use of incorporating experiments into the inductive teaching and learning process will be given.  We will give examples of experiments used in teaching Freshman Clinic, fluid mechanics, heat transfer and separations.  A major thrust of this paper will be to show why traditional experimental procedures need to be altered to fit into an inductive method.

We believe that this method of teaching appeals to the inductive learner which is the preferred method of most students. A deductive learner prefers to proceed from general to specific, while an inductive learner prefers to proceed from specific to general.  Studies have shown that induction promotes deeper learning and results in longer retention of the information to students.  Induction, in many cases, is also the method in which the original material was discovered!  This style of teaching is relatively rare in engineering courses and is almost non-existent in textbooks.

## INTRODUCTION

Instructors can teach inductively by presenting familiar phenomena, practical issues, or experimental observations before presenting a general principle.  This procedure is unfamiliar to most professors since they were taught using a deductive style in graduate and undergraduate school. Surprisingly, most textbooks still use an exclusively deductive approach, proceeding from first principles and governing equations to specific applications.  Since there are relatively few textbooks that are written using an inductive approach and a professors prior experience is deductive; this makes implementation of the inductive method a challenge.  Another challenge is that students typically will not have a wide range of experience or intuition needed to begin the inductive process.  A simple laboratory experiment or demonstration will provide the foundation (observations or data) from which the inductive process is initiated.  It is interesting to note that in elementary school the science subjects are being taught use a text written in an inductive style.[1]

We have integrated inductive learning into our coverage of Freshman Clinic, fluids, heat transfer and mass transfer.  In heat transfer, for example, simple heat exchanger design is the first topic addressed in the course.  Discussion of the significance of the overall heat transfer coefficient provides a meaningful framework for introduction of topics such as conduction and convection,

which are introduced later in the course. In mass transfer, presented in the context of a transport phenomena course, students start with the design of a gas absorption tower. They are shown both laboratory equipment and pictures of industrial towers used to remove an impurity from a gas stream. If possible, they perform experiments on a laboratory gas absorption tower and observe the gas and liquid flowing over the packing material and measure inlet and outlet gas concentrations. Next, they use a simple model of the tower with a constant overall transfer unit height. The students then proceed to learn about the overall mass transfer coefficients, individual phase coefficients, and the film theory of mass transfer. This portion of the material ends with an experiment in diffusion, Fick's law of diffusion and the measurement and prediction of a diffusion coefficient. A more detailed explanation of our heat and mass transfer courses is presented in an earlier paper.[2]

In conducting experiments in an inductive format we have found that the experimental write-up needs to be modified. This paper presents several examples of how traditional laboratory experiments are modified for use in inductive teaching. In addition, this paper will review how our introductory fluid mechanics course presentation has been modified to an inductive topic order.

## Inductive Learning and Teaching Styles - Background

Deductive teaching begins with rules or principles and then proceeds to deduce consequences or resulting phenomena. This is the natural teaching style in higher education, particularly in mathematics and engineering courses. Using a deductive teaching style, a professor can cover a large quantity of material in a short amount of time simply by lecturing and presenting derivations. Most topics in engineering courses are approached deductively; most courses are arranged in a deductive structure, and most curricula are organized to utilize a deductive order of courses.

Induction is the more natural *learning* style in which the learners explore observations and then infer the governing principles from them[3]. Children learn by observation, not by deriving outcomes by beginning with first principles. Once familiar with an outcome or phenomenon, a child's natural curiosity will lead him or her to ask for an explanation. The Scientific method also begins with induction when a scientist formulates generalizations that explain experimental observations. Those generalizations can then be extended and applied to other situations to deduce outcomes or describe phenomena. The concepts of inductive learning and deductive learning are illustrated in Figure 1.



Felder makes several observations about inductive and deductive learning [3, 4]:

- Students who prefer inductive learning (inductive learners) need motivation for theoretical material.
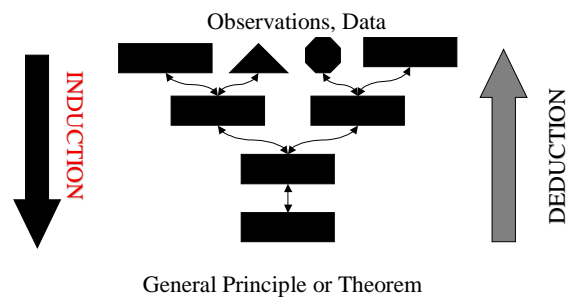
Figure 1: Deductive learning is begins with principles, and inductive learning begins with observations (Adapted from Felder et al.[4] ).

- Purely deductive teaching makes the students think that the material was straightforward for the instructor to develop (i.e., obvious)

- Purely deductive teaching leaves the student thinking that he or she could never come up with the derivation by him/herself.

- Deductive teaching may be more efficient for short-term retention.

- Inductive teaching is better for long-term retention and transfer of concepts.

- Everyone learns deductively and inductively.  Preference for one may be mild or strong.

In order to address both inductive and deductive learning styles, Felder and Silverman suggest approaching topics much as scientific method is used:  first by induction and then by deduction[3]. An in-class presentation of observable phenomena creates a framework for inferring general principles.  These governing principles can then be used to deduce other implications and consequences.  The authors then present an interesting approach to a fluid mechanics topic that addresses a variety of learning styles, including inductive learning.

In this paper, we present examples of using the inductive teaching style which incorporates laboratory experiments.  We also describe the inductive approach to individual topics in heat transfer and mass transfer.  We have found that this inductive approach to heat and mass transfer has naturally created opportunities for active learning via laboratory experiments and in-class discussions of experimental observations, thus contributing further to students' understanding and retention of new material as shown in Figure 2.
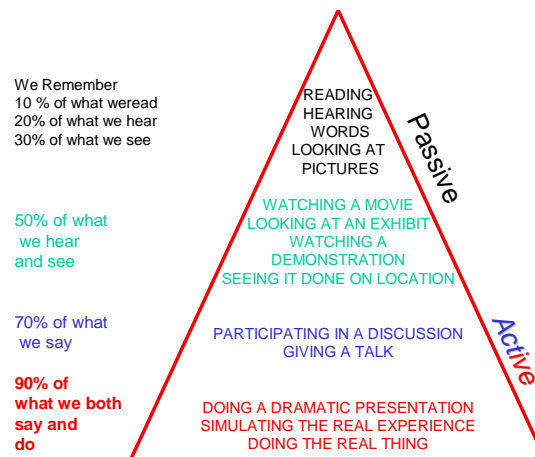


Figure 2:  Active learning contributes to student understanding and retention of new material.

**FRESHMAN CLINIC**

Rowan's two-semester Freshman Clinic sequence introduces all freshmen engineering students to engineering in a hands-on, active learning environment. Engineering measurements and reverse engineering methods are common threads that tie together the different engineering disciplines. Previous reverse engineering projects have involved common household products such as automatic coffee makers [5,6,7] hair dryers and electric toothbrushes [8]. Using common products with which the students are already familiar is thought to present a framework within which new concepts can be introduced.

Recently, a new engineering system was added to the list of familiar products for reverse-engineering investigation: the human body. This incredible machine can be explored using engineering measurements and analyzed using engineering principles. Basic physiologic responses are already familiar to students through "common knowledge" and sensory experiences, and most students have a natural curiosity to learn how their own bodies work. In reverse engineering the human body, we use non-invasive measurements to quantify physiologic properties and responses. In a series of hands-on modules, students investigate several interacting systems within the human body: the respiratory system, cardiovascular system, metabolic system, and thermoregulatory system.

To set the stage for the investigations of these interacting systems, students perform a short exercise protocol (jumping jacks or running) and then make observations about their breathing rate, heart rate, and heat transfer rate. These qualitative, sensory observations are used to start a discussion on the interactive functions of respiration, circulation, metabolism, and thermoregulation. This helps establish the "big picture", and provides the framework for further investigation. Next, a hands-on experiment is conducted in which physiologic variables such as breathing rate, and respiratory gas compositions at rest and during moderate exercise on an exercise bicycle ergometer. Using their data, students perform mass balances to determine the rates of oxygen consumption and carbon dioxide production. Their calculations confirm that the increased breathing rate during exercise results in an increased rate of oxygen consumption (and carbon dioxide production). In the metabolism investigation, these data are used to calculate the rate of energy expenditure (as food is burned with oxygen to generate energy)), and to determine the mechanical efficiency of the human body. The role of respiration in thermoregulation is explored by applying energy balances to determine sensible and latent heat transfer rates through respiration, and to compare these to the total energy expenditure. In exploring the cardiovascular system, blood flowrate and blood pressure are measured non-invasively, and are used to calculate the pump work of the heart at rest and during exercise. Typical student results are shown in **Table 1**.

**Table 1**. Typical student results for resting and exercise experiments: rate of oxygen consumption during respiration, rate of energy expenditure in metabolism, mechanical efficiency of cycling activity, blood flowrate, average blood pressure, rate of work of the heart, and the rate of heat transfer by respiration.

| | $\dot{V}_{O2}$ (L/min) | Energy Expenditure Rate (kcal/h) | Mechanical Efficiency | $\dot{V}_{Blood}$ (L/min) | $BP_{avg}$ (mmHg) | $\dot{W}_{heart}$ (kcal/h) | $HT_{resp}$ (kcal/h) |
|---|---|---|---|---|---|---|---|
| Rest | 0.25 | 74.0 | | 5.0 | 93.3 | 0.89 | 10.4 |
| Exercise (30 W) | 0.63 | 185.0 | 0.25 | 8.0 | 107.0 | 1.64 | 26.1 |

**FLUID MECHANICS**

At Rowan University we teach the subject of fluid mechanics starting with a 2 credit hour introduction to fluids, a 2 cr. hr. advanced fluids course, approximately 1 credit hour in a Transport Phenomena course, and additional fluids topics in a chemical process equipment design course. Our fluid mechanics sequence is summarized in Table 2. In the Spring semester of 2001 the introductory fluids course, Fluid Mechanics I, was taught in an inductive topic order.

**Table 2: Fluid Mechanics at Rowan University**

| Semester | Course | Credit Hours |
|---|---|---|
| Sophomore Spring | Fluid Mechanics I | 2 |
| Junior Fall | Process Fluid Transport | 2 |
| Senior Fall | Transport Phenomena Chemical Process Component Design | 1 out of 3 0.5 out of 4 |

In this course we use the paperback text by Young et al.[9]. This text was chosen based on the quality of the writing, example problems and homework problems. Students in general find this text easy to read and very helpful. The text is not a chemical engineering text since the Moody friction factor and not the fanning friction factor is presented. Of use for the inductive teaching method is the CD-Rom that accompanies the book. This CD contains many movies of experiments that can be shown using a computer projection system in class.

The overall topic order in the Fluid Mechanics I course is as flows:

- fluid flow without friction (Bernoulli without friction)

- fluid flow with friction (Bernoulli with friction)

- momentum balance

Using this topic order the coverage of the text starts with Chapter 3 followed by 8 and 5.

**Bernoulli Experiments**

This manner was chosen so that experiments illustrating Bernoulli equation will begin the course. These simple Bernoulli experiments are shown in Figure 3 and include

1. blowing over the top of a piece of paper which is held between your fingers. This causes the paper to rise.

2. Ping Pong ball experiments:

   2.1. Ping pong ball in a funnel with an air stream blowing upwards

   2.2. Two ping pong balls suspended from strings with a jet of air blowing between the balls

   2.3. ping pong ball suspended by a free jet of air

   2.4. ping pong ball suspended by a free jet of air that is included
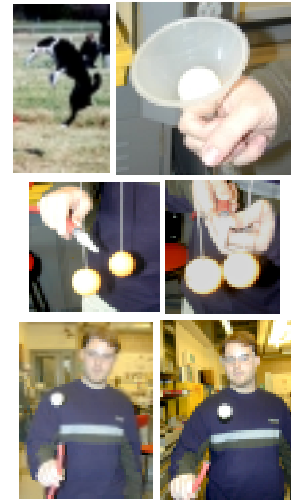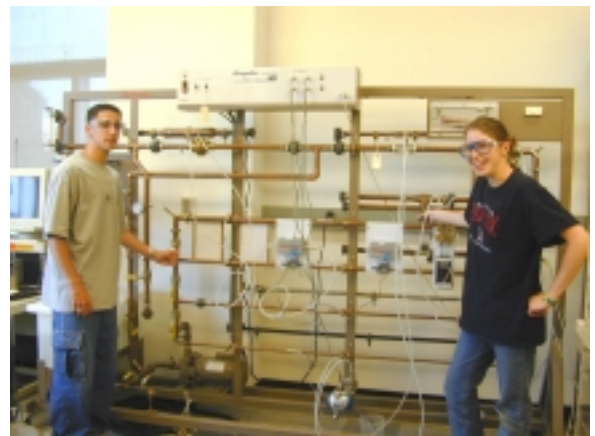
3. Frisbee



Figure 3: Simple Bernoulli Experiments

During this laboratory session students make observations of the phenomena and record them in a laboratory write-up. Following this laboratory a discussion of their observations leads to a summary of the observed effects which is followed by a presentation of the Bernoulli Equation and appropriate homework problems.
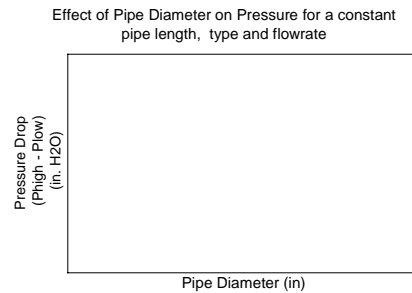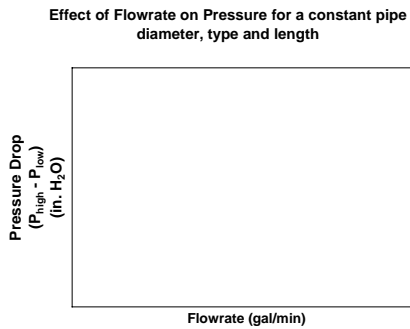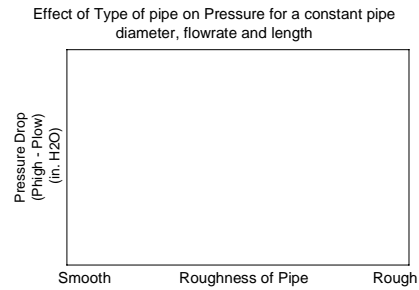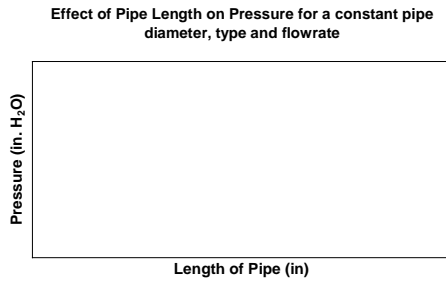
**Pipe Flow Experiments**

The next section starts with a set of experiments using our pipe flow equipment. The traditional pipe flow laboratory has the students take pressure drop readings at a given set of flowrates, pipe diameters, and pipe materials. The students then take these readings and determine the friction factor and compare it to the published charts.

To alter this experiment for the inductive method the students perform the same lab, but the analysis is spread out over several homework assignments. The students begin the inductive experiment by reading the handout and making predictions of what they think will happen in the laboratory.

Make sketches of the following:

**Effect of Pipe Length on Pressure for a constant pipe diameter, type and flowrate**

Pressure (in. H$_2$O)

Length of Pipe (in)

**Effect of Type of pipe on Pressure for a constant pipe diameter, flowrate and length**

Pressure Drop (Phigh - Plow) (in. H2O)

Smooth        Roughness of Pipe        Rough

**Effect of Flowrate on Pressure for a constant pipe diameter, type and length**

Pressure Drop ($P_{high}$ - $P_{low}$) (in. H$_2$O)

Flowrate (gal/min)

**Effect of Pipe Diameter on Pressure for a constant pipe length, type and flowrate**

Pressure Drop (Phigh - Plow) (in. H2O)

Pipe Diameter (in)

By making the above sketches the students become interested in seeing if they guessed the correct behavior. This turns the laboratory from a laborious task of collecting a large number of pressure drops at different flowrates. As the laboratory data is collected the students are asked to make the above plots on the laboratory computer (excluding the roughness plot). They are required to turn in the following plots as part of a laboratory write-up:

a) Graph 1: Pressure drop as a function of flowrate for brass pipes. Use a separate data series for each pipe diameter.

b) Graph 2: Pressure drop as a function of the *square of the flowrate* for brass pipes. Use a separate data series for each pipe diameter.

c) Graph 3: Pressure drop as a function of flowrate for pipes of different materials but have the same diameter. Again use a separate data series for each pipe material.

d) Calculate the values of $\Delta P/L$ for both pipe lengths (*pressure drops are measured for 2 ft and 4ft segments*).
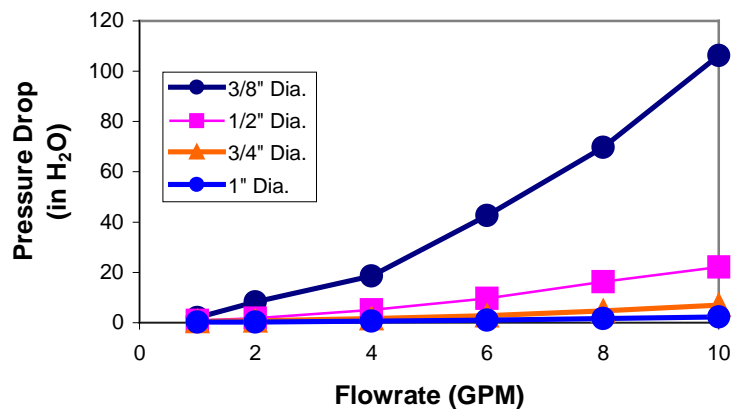
e) Calculate the Reynolds number

Figure 4: Pipe flow experiment for pressure drop measured over a 2 ft section of brass pipe.

for each run.  Make sure to correct the density and viscosity of water for any variation caused by a change in temperature during your run.

In the lecture session following this laboratory is a discussion of the above results (similar to that shown in Figure 4 and Figure 5) and a correlation of the data.  For example typical observations by the student:



1.  Pressure decreases or drops as fluid flows down a pipe. Question evoked:  Does the velocity drop as well?  This will result in a discussion centering on a mass balance.

Figure 5:  The relationship between velocity squared and pressure drop

2.  The pressure drop in a pipeline is inversely proportional to the diameter of the pipe. An analogy to the size of a road can be made.

3.  The pressure drop in a pipeline is proportional to the length of pipe and the square of the velocity.  Again a road type analogy can be made to the length of the road.
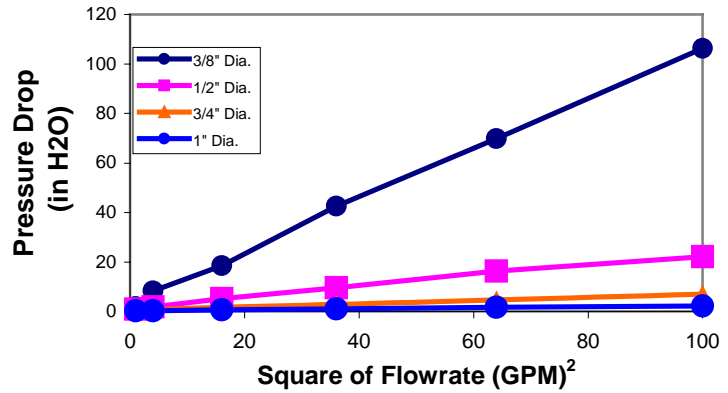
After this laboratory an in-class discussion should be initiated in which the students are given that the relationship between these variables as given by equation (1)

$$P_1 - P_2 = 2\rho \sum_{i=1}^{n} f_{F_i} v_i^2 \frac{L_i}{D_i} \tag{1}$$

As a homework exercise they should calculate the value of the friction factor and determine the dependence of the friction factor on other variables or parameters such as the Reynolds number. This could be followed by asking the student to compare the values obtained with a fanning friction chart and a fanning friction factor correlation. Finally an examination of pressure drop on the roughness of the pipe can be conducted.  A typical homework assignment given in our class is:

1.  Calculate the fanning friction factor for each of your runs using the pipe pressure drop, length, diameter, and flowrate.  Remember to use the actual pipe ID for your calculations (*e*.g. don't use the nominal diameter.)
2.  Construct a plot of $f_{fanning}$ *vs*. Re for all of the runs.  Plot the points obtained for each flowrate.  Use a different color marker for copper, stainless and other pipes.
3.  To the above graph add the predictions of one of the following fanning friction factor equations
    3.1.  Colebrook (eqn 6-38 in Perry's),
    3.2. Colebrook and White (eqn 5-47 in Cutlip and Shacham)
    3.3. Shacham (p177 in Cutlip and Shacham)

Plot the predicted friction factor for each pipe type.  Represent the output of this equation using a line with the same color as the markers above.
4.  Write a paragraph comparing your experimental results with the predictions from the above correlation.

Now the student should have a firm understanding of the relationship between pressure drop and flowrate within a pipeline.  This is one of the basic aspects of fluid mechanics that all chemical engineers should be able to apply to a process.  Using an inductive order will increase the number of students in a class that have attained this level of understanding.

The fluid mechanics class continues with similar procedures for experiments:
- pressure drops in fittings and valves
- flowmeters
- Momentum balances

Teaching the class in this manner does not increase the number of laboratories that are given, assuming that laboratories are already part of the class.  Instead the approach is to use the laboratory as a method to discover relationships.  This discovery phase will add active learning to reinforce the basic principles of fluid mechanics.

**HEAT TRANSFER**

In order to introduce an inductive approach to the structure of the heat transfer course that is offered in the fall of the junior

year, the class begin with a discussion about heat exchangers. On the first day of class, students visit the laboratory where they observe the operation of a shell and tube heat exchanger. Returning to the classroom, students explore the application of the performance equation for single pass heat exchangers:



Figure 6:  Shell and Tube Heat Exchanger

$$q = UA\Delta T_{LM} \qquad\qquad (2)$$

Equipped with this simple equation, students investigate the effect of each variable:  How does the heat exchanger area (A) affect the rate of heat transfer (q) or one of the outlet temperatures? What is the effect of the value of the overall heat transfer coefficient, U?  Students are also introduced to the units of the heat transfer rate and the overall heat transfer coefficient, and they are familiarized with representative values of the overall heat transfer coefficient as presented their textbook by Incropera and DeWitt[10].  Students work modified example and homework problems from Chapter 11 of their textbook in which they choose typical values of the overall heat transfer coefficient instead of calculating it by traditional methods (as they will later in the course).

Once they are comfortable with the application of the performance equation and the effects of the different variables, the mechanisms of heat transfer occurring inside the heat exchanger are introduced. In this introductory heat transfer course, these include only conduction and convection. Students have a basic qualitative understanding of conduction and convection, and are able relate this to the relatively new application of heat exchangers. Students are presented that both mechanisms of heat transfer, conduction and convection, have an impact on the overall heat transfer coefficient. This establishes a framework for the remainder of the course, and provides motivation for the exploration of the individual mechanisms of heat transfer.



Figure 7: Armfield Conduction Experiment

As conduction and convection are explored in depth throughout the course, these topics are always introduced by their relevance to the now familiar heat exchanger.

As suggested by Felder and Silverman[3] individual topics can be addressed first by induction and then by deduction. Conduction is introduced first by a class discussion of their experiences with conduction: cooking with a metal spoon and grabbing a handle that is too hot (this would not happen with a wooden spoon), adding new insulation to a house to lower energy costs of heating and cooling. The relevance to conduction of heat through the wall of a pipe in a heat exchanger is emphasized. Following this discussion of conduction, the students proceed to the laboratory where they rediscover Fourier's Law by performing an experiment. The experiment is performed on an Armfield HT11 Linear Heat Conduction apparatus. The apparatus consists of an electrical heat source (students can set the voltage, measure the current, and calculate the power input), a material sample (brass, aluminum, stainless steel, cork, or paper), and a heat sink. The samples are insulated to ensure one-dimensional heat transfer from the heat source toward the heat sink. Students measure steady-state temperature profiles through the samples, and discover that these temperature profiles are linear as shown in Figure 8. They discover that, for a given material sample, the temperature gradient is proportional to the heat input. They learn that the same heat input will result in different temperature gradients in different samples. They compare the different temperature gradients that result from using different samples. For homework, they graph their temperature profiles (Temperature vs. distance from heat source) and calculate the slope $\dfrac{\Delta T}{\Delta x}$. In the next class they are supplied with tabulated values of thermal conductivity (k), and discover that these values represent the proportionality constant that relates the value of heat input to the resulting temperature gradient for a given material. In short, they have rediscovered Fourier's Law.
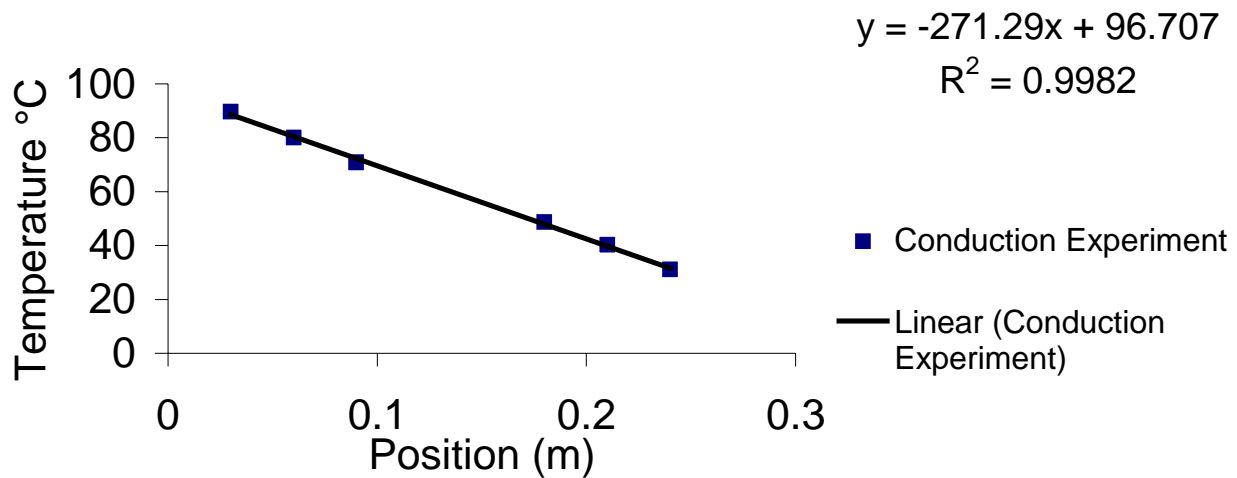
$$y = -271.29x + 96.707$$
$$R^2 = 0.9982$$

Figure 8:  Conduction in Brass Sample

The topic of natural and forced convective heat transfer begins with a discussion of familiar examples of convection.  How long does it take to cook a potato in boiling water ($100^{o}$C)?  How long does it take to cook a potato in an oven at 200°C?  Do you feel colder standing outside on a cold windy day, or on a cold day without wind?  Why do children blow on a hot spoonful of soup before eating it?  Following this discussion, students investigate convective cooling by performing an experiment in which they investigate the cooling of a hot cup of coffee[11].  They discover that the rate of cooling is faster initially, when the coffee is hotter, and slows down as the coffee cools.  This provides the framework for the presentation of Newton's Law of Cooling and the quantitative treatment of natural and forced convection systems.

**SEPARATION PROCESSES**

This course integrates several small demos and experiments.  The lectures on diffusion are supplemented with some in class demonstrations of diffusion of dye in water with and without mixing.  Then colored crystals are dissolved.  This shows students the effect of mixing on mass transfer coefficient.  Different everyday examples of diffusion in different types of materials are show; perfume use, drying paint, cut fruit, curing of timber, etc.  A demonstration on chromatography has been introduced in which the components of grape soda are eluted (separated).   A small-scale reverse osmosis experiment, designed by Dr. Slater with NSF funding, has been incorporated into the course.  This experiment shows the basic transport parameters in the separation of a simulated industrial waste stream.  An ultrafiltration experiment has been integrated that shows the separation of a pharmaceutical system .  In this case a mixture of vitamin B-12 and Dextran blue (2000) has been used.

**Student Comments and Professor Evaluation**

The students in the fluid mechanics class were asked to comment on the inductive topic order and positive responses were elicited from the students.  In response to the question: **Please comment on how the inductive order of topics used in this class aided your learning of the**

**subject matter of Fluid Mechanics. In general, the class topics were covered placed in the format similar to the following sequence: Equipment and/or demonstrations => Fluid Flow Experiments => application of principles to solve engineering problems => Analysis of Experiments => fundamentals of fluid mechanics.**

Students comments included:
1. This order was very good for me, I learned a lot this semester and everything seemed to be in appropriate order.
2. I think this is a good way to teach. Once a student can picture an application of a mathematical model, the student can understand it better.
3. I really enjoyed and understood this way of teaching. It was very beneficial seeing how things behaved then learning why. You could follow by visualization and that really helped me conceptualize the equations.
4. I have an excellent understanding of fluid mechanics because of the order it was shown to me. When I see an equation I can also see a picture of what is happening to the fluid because of the experiment I have done. I wish all of my classes were taught this way.
5. I liked this method because it started with the basic and gradually got more complicated.
6. It was fine.
7. Possibly the most effective method of teaching I have ever experienced.
8. The labs helped to reinforce what we learned in lecture. And seeing simpler problems that led to more complicated equations and theories works much better than working in the opposite direction.
9. I liked this inductive method. I found new concept to make more sense physically, rather than just theoretically, due to the demonstrations. Although the analysis tended to be a bit thorough at times.
10. Interesting
11. It was ok I guess
12. This order seemed to make logical sense and helped you understand what you were learning.
13. The topics were well organized and followed a logical order. It was easy to follow them as presented.
14. I like the way the class flowed. I felt prepared for each new topic as we covered it.
15. I found that I was able to pick up the topics fairly well.

Of the 19 students in class 3 responses were neutral commented that they did not understand what they were supposed to learn from the laboratories. One student did not like this order of topics.

In a separate question asking the student to rate their improvement in applying and comprehending the principles of the Bernoulli equation, mechanical energy balance and momentum balance a dramatic improvement was given by the students in each of these areas.

The question asked:
3. Please rate your level of applying and comprehending the following principles based on the metric given below.
    1. I can apply this equation to fluid flow problems that I have not seen before without using the text.
    2. I can apply this equation to fluid flow problems that are similar to those that I have seen before with out using the text.
    3. I can apply this equation to fluid flow problems that are similar to those that I have seen before with the aid of the text.

4. I can calculate the appropriate variables using this equation after it has been applied to a particular problem.
5. I could not identify the appropriate values to use in this equation, even if the problem was set up for me by someone else.

| Principle | Before taking this class (average class rating) | After taking this class (average class rating) |
|---|---|---|
| Bernoulli Equation | 4.1 | 1.1 |
| Mechanical Energy Balance | 4.4 | 1.2 |
| Momentum Balance | 4.5 | 1.4 |

Based on these results the students could apply Bernoulli and mechanical energy balance equations to fluid flow problems that they have not seen before without using the text. For the Momentum balance about half the students felt that they could apply the momentum equation to problems similar to what they have seen before and the other half to new problems without using the text.

In summary, the above analysis was shows that a majority of students prefer having an inductive order and presentation of topics.

**Future Teaching Plans**

This paper discusses the use of the inductive style in chemical engineering courses and gives examples of how a traditional laboratory should be modified to an inductive style. To convert a laboratory write-up to an inductive style the following should be done:
1. Handout a prelab given to peak the students interest. Have them hypothesize the trends in the data that will be collected.
2. The laboratory work should primarily consist of data collection and analysis using only graphical methods.
3. Discussion of the lab should take place in the classroom setting. Variable-parameter relationships should be identified.
4. Lectures on the variable-parameter relationships should be given.
5. Homework should be assigned based on the data taken in the laboratory.

In the procedure for an inductive presentation style of material starts with an experiment or shows results of an experiment and ends with the derivation of equations describing these results. The second concept presented in this paper is an inductive order of topics within an area of fluids. For example fluids could be taught starting with fluid flow without friction to fluid flow with friction to momentum balances. Each of the lectures presented in this novel topical order could be done in an inductive manner; starting from experimental observations and ending with a derivation of the governing equation. We believe that this inductive style of teaching will result in large gains in the student's ability to synthesize and evaluate this material.

## Acknowledgements

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## BIOGRAPHICAL INFORMATION

**Stephanie Farrell** is Associate Professor of Chemical Engineering at Rowan University. She received her B.S. in 1986 from the University of Pennsylvania, her MS in 1992 from Stevens Institute of Technology, and her Ph.D. in 1996 from New Jersey Institute of Technology. Prior to joining Rowan in September 1998, she was a faculty member in Chemical Engineering at Louisiana Tech University. Stephanie's has research expertise in the field of

drug delivery, and integrates pharmaceutical and biomedical topics and experiments into the chemical engineering curriculum. Stephanie won the 2000 Dow Outstanding Young Faculty Award, the 2001 Joseph J. Martin Award, and the 2002 Ray W. Fahien Award.

***Robert Hesketh*** is a highly motivated professor in both undergraduate and graduate education and has received 9 education and 2 research awards, including ASEE's 1999 Ray W. Fahien Award.  He has made major contributions in laboratory methods that demonstrate chemical engineering practice and principles.  These highly visual and effective experiments, the most notable using the vehicle of a coffeemaker, are used to introduce engineering design and science to university and pre-college students.  He has developed over 20 experiments employed throughout the curriculum at Rowan University.  These experiments range from small scale coffee experiments to 25 ft distillation column experiments. His work has been presented at national meetings, workshops and published in journals and proceedings and his experiments are being used in over 15 institutions.  He has attracted over 2 million dollars in external funding for research and educational activities.