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The Greening of Chemical Engineering Students

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This work examines the incorporation of green engineering concepts into a traditional, design-oriented heat transfer course for chemical engineering students. Two of the 24 problems developed to cover 13 chapters in the widely used heat transfer textbook, *Fundamentals of Heat and Mass Transfer* by Incropera and DeWitt in conjunction with the green engineering text *Green Engineering – Environmentally Conscious Design of Chemical Processes* by Allen and Shonnard are presented here. In general, the problems contain two components - typical heat transfer design calculations and a green engineering analysis of that design. The problems may be either used in their totality or the green engineering component may be used alone. This work also presents the assessment of the incorporation of green concepts into a traditional course. The assessment tools include multiple student surveys and a two-page green engineering analysis submitted by each student in the class. The results show that the use of greened homework problems increased the awareness of the students in the course to a variety of green engineering concepts.

Introduction

Although the United States Environmental Protection Agency was created in the early 1970s and environmental regulations have been around since the mid 1960s, the concept of green engineering did not gain prominence until the mid 1990s.[1] Green engineering has been described as the incorporation of environmentally conscious attitudes, values, and principles into engineering design toward a goal of improving local and global environmental quality.[1, 2] This work examines the incorporation of green engineering concepts into a traditional undergraduate chemical engineering course and the assessment of that integration by examination of the feedback loop highlighted by the dashed enclosure in Figure 1.

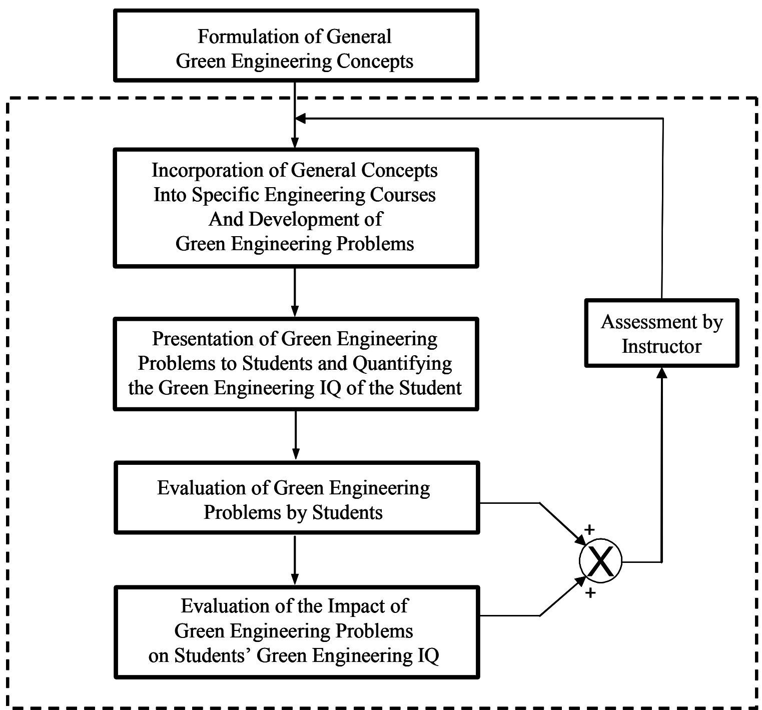

Figure 1. The Implementation of Green Engineering Concepts into a Traditionally Design-Oriented Heat Transfer Course

The first part of this work examines how green engineering was incorporated into a fundamentally design-oriented, heat transfer course for undergraduate chemical engineering students. Homework problems were developed for the course that consisted of two parts. The first part addressed key heat transfer design concepts such as conduction and convection resistance, overall heat transfer coefficients as well as standard heat exchanger design such as double pipe and shell & tube. The second part of each problem then addressed the impact of that design on a specific environment. For example, the first part of a given problem might require the student to calculate the necessary insulation thickness for an underground heated transfer line. The second part of that same problem would then require the student to discuss the possible consequences of placing the transfer line near a densely populated area susceptible to earthquakes. A total of 24 problems were developed to cover 13 chapters in the widely used heat

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transfer textbook, *Fundamentals of Heat and Mass Transfer* by Incropera and DeWitt in conjunction with key green engineering concepts outlined in *Green Engineering – Environmentally Conscious Design of Chemical Processes* by Allen and Shonnard.[3, 4] Two sample problems are presented here but the entire problem set with solutions may be found at www.rowan.edu/greenengineering.

In order to evaluate the internalization of the concept of green engineering by the students, the second part of this work examines how the "Green Engineering I.Q." of 27 undergraduate chemical engineering students progressed during the course of a 14 week semester into which a portion of the 24 green engineering problems were incorporated. At the beginning of the semester, the students were asked to rate their own environmental awareness on a scale of 0-10, i.e., quantify their green engineering IQ. Over the course of the semester they were also asked to rate each green engineering problem assigned to them with respect to how it affected their green engineering IQ. Finally, each student was required to submit a two-page green engineering Analysis at the end of the semester outlining how (if at all) the green engineering portion of the course affected his or her environmental attitudes, values and principles and how (if at all) their green engineering IQ was altered, using specific green engineering problems to reinforce their claims. Finally, the student surveys of the greened homework problems and their green engineering IQ along with the students' green engineering analyses were used by the instructor to assess and modify the greened course.

Incorporation of Green Engineering Concepts and Development of Green Engineering Problems

The chemical engineering undergraduate program at Manhattan College revolves around a design oriented curriculum and as a result, the idea of incorporating green engineering concepts into a heat transfer course that has a particularly strong emphasis on design seemed difficult – at first. The course is offered during the fall semester of the junior year and one of its primary goals of the course is to prepare the students for a one-year plant design course in the student's senior year. As previously stated, typical design elements included the calculation of convective and overall heat transfer coefficients as well as the design of a variety of heat exchangers. During the development of the problem set, *typical* questions such as "How do you green a metal shell & tube heat exchanger" arose. As a result, *typical* answers such as "Increase the heat recovery, use better insulation" followed. It was difficult to imagine the development of a problem set for an entire course that centered on single concepts such as heat recovery and insulation. Therefore, instead of greening the *fundamentals* of heat transfer design it was decided to green the *results* of heat transfer design. In other words, it was decided to develop a heat transfer problem set that continued to focus on the necessary, traditional design concepts in the curriculum with the additional condition of requiring the students to examine the environmental impact of that design. As a result, and as explained earlier, most of the greened heat transfer problems consisted of two distinct parts: the quantitative, traditional design calculations followed by a more qualitative, environmental impact analysis of that design. This approach is illustrated in two of the more popular problems (with solutions) presented below. Each problem references the appropriate section(s) in the Incropera & DeWitt text as well as the Allen & Shonnard text.

PROBLEM 1

The Conduction Shape Factor and the Importance of Rainforest Conservation

Incropera & DeWitt: 4.3
Allen & Shonnard: 1.7

When this problem was first distributed to the students in class, it was necessary to give a brief description of a rainforest following a brief overview of the problem statement (which included a pipeline construction). Luckily, the reality of the problem was reinforced by the TA for the course who happened to be a Venezuelan native.

Part a.) of this problem requires the student to calculate the resistance due to the soil, magnesia, and calcium silicate and determine the heat transfer rate from the pipeline using two different configurations. Calculating the heat transfer rate from a pipe (regardless of where the pipe is located) or the insulation required around a pipe is a typical exercise given to an engineering student. Most of the properties that are needed can be found in the appendix of Incropera & DeWitt. However, the answers to parts b.) and c.) certainly cannot be found in any standard textbook and requires the student to think (at a minimum) and search the library or internet for possible answers. Indeed, the students' answers to parts b.) and c.) for this particular problem were much more exhaustive than the solution provided and included much personal reflection given the high potential for loss of human life and destruction to natural resources.

Problem Statement

Faced by what is perhaps Ecuador's severest economic crisis of this generation, the government of Ecuador has come up with a plan to double its export of oil. Construction of a new, above ground oil pipeline, the OCP (Oleoducto de Crudo Pesado, or Heavy Crude Pipeline) will make it possible to open up vast new areas of the Amazon to oil exploration. Efficient transportation of the crude requires that the temperature of the crude remain above its pour point. Below its pour point of 35°C, the crude takes on a wax-like consistency. The crude enters the OCP at 70°C, the temperature is monitored until it begins to approach its pour point ($T_{oil} \approx 40°C$), at which point steam is injected to raise the temperature of the crude back up to 70°C. This proposed pipeline will pass through eleven natural reserves and "protected" areas. Schedule 80 pipe (12 inch) is used to transport 840,000 gal/day of crude. Assume the average temperature of the ambient air is 30°C (h = 6 W/m^2-K). The following crude oil data is available: c_p = 2047 J/kg-K, ν = 0.839E-04 m^2/s, ρ = 0.864E03 kg/m^3 , k = 0.140 W/m-K, Pr = 1050.

a.) Compare the distance between steam injections for an uninsulated pipe to a pipe that is insulated with 3 inch standard fiberglass insulation (k = 0.035 W/m-K).

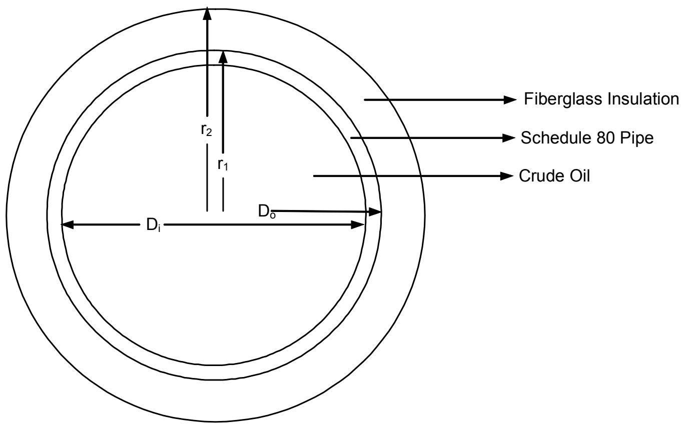
b.) What are the environmental hazards associated with invading these rainforests and "protected" areas in order to build this pipeline?

c.) What are the dangers associated with building this pipeline if it is to pass through cities and near local water supplies? Since this area sustains many earthquakes, landslides and soil shifting, what would be the consequences of a pipeline rupture?

Solution

a.) Find: Find the distance traveled by the crude before the temperature drops from 70°C to 40°C. Compare uninsulated to insulated pipe.

Schematic:



Assumptions:
1. Steady-state conditions.
2. Negligible resistance through pipe wall.
3. One-dimensional conduction through the insulation.
4. Constant properties.

Analysis:

Find the convection heat transfer coefficient for the crude oil, h_i:

Volumetric flow rate, F = 840,000 gal/day = 0.037 m^3/s

Pipe ID, D_i = 0.9478 ft = 0.289 m

Pipe OD, D_o = 1.058 ft = 0.323 m

Velocity, $v = \frac{4 \cdot F}{\pi \cdot D_i^2}$; $v = 0.561$ m/s

$$Re = \frac{v \cdot D_i}{\nu}; \quad Re = 1.933x10^3; \quad Pr = 1050$$

$$Nu = 0.023 \cdot Re^{0.8} \cdot Pr^{0.33}; \quad Nu = 97.22$$

$$h_i = \frac{k_{oil}}{D_i} \cdot Nu; \quad h_i = 47.114 \frac{W}{m^2 \cdot K}$$

Find the overall heat transfer coefficient, U:

Inside radius of insulation, $r_1 = \frac{D_o}{2}$

Insulation thickness, t = 3 inches = 0.076 m

Outside radius of insulation, $r_2 = r_1 + t$

$$U = \frac{1}{\frac{1}{h_i} + \frac{r_1 \cdot \ln\left(\frac{r_2}{r_1}\right)}{k_i} + \frac{r_1}{r_2 \cdot h_{air}}}$$

$$U = 0.516 \frac{W}{m^2 \cdot K}$$

Find the log mean temperature difference, LMTD:
Inlet temperature of the crude, $T_i = 70°C = 343K$
Exit temperature of the crude, $T_o = 40°C = 313K$
Temperature difference between crude and air at inlet, $\Delta T_i = T_i - T_{air}$
Temperature difference between crude and air at exit, $\Delta T_o = T_o - T_{air}$

$$LMTD = \frac{\Delta T_i - \Delta T_o}{\ln\left(\frac{\Delta T_i}{\Delta T_o}\right)}; \quad LMTD = 21.64K$$

Find the length of pipe, L, traveled by crude before temperature drops from 70°C to 40°C:
Heat lost by crude, $Q = \rho \cdot F \cdot c_p (T_i - T_o); \quad Q = 1.953x10^6$ W

$$L = \frac{Q}{U \cdot 2\pi r_2 \cdot LMTD}$$

$L = 1.172x10^5$ m = 117.2 km at insulation thickness, t = 3 inches

Find the length of pipe, L, traveled by crude before temperature drops from 70°C to 40°C when insulation thickness, t = 0 (i.e, $r_2=r_1$):
L = 16.7km at t = 0 inches

Additional results:
L = 65.1km at t = 1 inch
L = 96.4km at t = 2 inches

b.) Environmental hazards associated with rainforest deforestation:

- Rainforests once covered 14% of the earth's land surface; now they cover only 6% and experts estimate that the last remaining rainforests could be consumed within 40 years.
- Nearly half of the world's species of plants, animals and microorganisms will be destroyed or severely threatened over the next quarter century due to rainforest deforestation.

- As the rainforest species disappear, so do many possible cures for life-threatening diseases. Currently, 121 prescription drugs sold worldwide come from plant-derived sources (70% of these plants come from the rainforests).
- Rainforests provide the essential world service of continuously recycling carbon dioxide into oxygen.
- One-fifth of the world's fresh water is in the Amazon Basin.
- At least 80% of the developed world's diet originated in the tropical rainforest. Many fruits, vegetables and nuts.
- 70% of the 3,000 plants that are active against cancer cells are located in the rainforest.

c.) Potential dangers of a ruptured pipeline:
- Releases of oil from pipelines can contaminate drinking water and crops.
- Pipeline ruptures can cause extensive property damage.
- Pipeline ruptures can kill fish and wildlife.
- Pipeline ruptures cause explosions and fires, which can put people in harm's way.
- Pipeline ruptures cause air pollution.

PROBLEM 2
Natural Convection and Energy Efficient Lighting

Incropera & DeWitt: 9.6
Allen & Shonnard: 1.3

This problem generated much less discussion when it was initially distributed to the class compared to Problem 1. In addition, the solution to parts a) and b) were very typical of design problems that dealt with convective heat transfer from a sphere. However, the discussion that accompanied the solution to part c) was very spirited when the students handed in their own solutions – having spent time researching the subject. The students' thoughts varied from shock at the sheer waste of energy associated with an incandescent bulb to a sense of inconvenience associated with the difficulties of applying make-up with fluorescent lighting. Most importantly, though, the question provoked a lot of thought.

Problem Statement

Lighting directly affects our economy. As a nation, we spend approximately one-quarter of our electricity budget on lighting, or more than thirty-seven billion dollars annually. An incandescent light bulb is highly inefficient because it only converts a small amount of the electrical energy into light (the rest is converted to heat). However, the relatively inexpensive purchase price of incandescent bulbs is what accounts for their popularity amongst consumers.

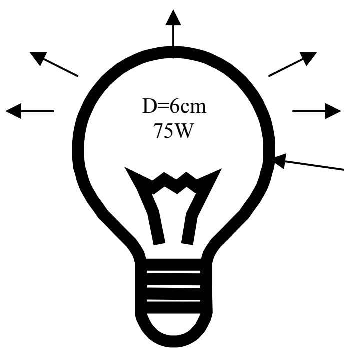
A 75W bulb that is assumed to have the shape of a sphere has a diameter of 6cm and a surface temperature of 250°C when the light is on. The surrounding air temperature in the room is 25°C.

a.) Determine the rate of heat transfer from the incandescent light bulb to its surroundings.
b.) Compact fluorescent light bulb products generate approximately seventy percent less heat than standard incandescent lighting. Determine the rate of heat transfer from the fluorescent bulb to the surrounding air.
c.) Explain why fluorescent lighting might be preferred over incandescent lighting from an environmental perspective.

Problem Solution

Find: The rate of heat transfer from an incandescent bulb to its surroundings:

Schematic:



Assumptions:
1. Steady-state conditions.
2. Air is an ideal gas with constant properties at a pressure of one atmosphere.
3. The light bulb is considered to be a 6cm sphere.

Properties:
The properties of air at one atmosphere and a film temperature of $(T_\infty + T_S)/2 = (250 + 25)°C/2 = 137.5°C + 273.15 = 410.7K$ are: (Table A-4: Incropera & DeWitt)

$k = 0.03273$ W/m-K
$\nu = 2.487E\text{-}5\ m^2/s$
$Pr = 0.693$
$\beta = 1 / T_f = 0.002593/K$

Analysis:
a.) Find the Raleigh Number:

$$Ra = \frac{g\beta(T_s - T_\infty)D^3}{\upsilon^2}Pr = \frac{(9.81\,m/s^2)(0.002593/K)(523-298)K(0.06\,m)^3}{(2.487E-5\,m^2/s)^2}(0.693)$$

$$Ra = 1.385E6$$

Using the Churchill correlation for spheres find the Nusselt Number:

$$Nu = 2 + \frac{0.589Ra_D^{1/4}}{[1+(0.469/Pr)^{9/16}]^{4/9}} \qquad Pr \geq 0.7 \quad Ra \leq 10^{11}$$

Although Pr is slightly below 0.7, this correlation is used as a close approximation:

$$Nu = 2 + \frac{(0.589)(1.385E6)^{1/4}}{[1+(0.469/0.693)^{9/16}]^{4/9}}$$

$$Nu = 17.549$$

Find the characteristic length in order to find the natural convection coefficient:
The characteristic length of a sphere is equal to the diameter of the sphere.
$L_c = D = 0.06m$

Find the natural convection coefficient:

$$h = \frac{k}{L_c} Nu = \frac{(0.03273W/m-K)}{(0.06m)}(17.549)$$

$$h = 9.573W/m^2{-}K$$

Find the surface area of the bulb:

$$A_s = \pi D^2 = \pi(0.06m)^2$$

$$A_s = 0.01131m^2$$

Find the rate of heat transfer from the bulb to surrounding air via convection and radiation:
ε(light bulb) = 0.95

$$q_i = hA_s(T_s - T_\infty) + A_s\varepsilon\sigma\left(T_s^4 - T_\infty^4\right)$$

$$q_i = \left[(9.573W/m^2{-}K)(0.01131m^2)(523-298)K\right] + \left[\left(0.01131m^2\right)\left(0.95\right)\left(5.67E-08W/m^2-K^4\right)\left(523^4-298^4\right)\right]$$

$$q_i = 24.36W + 40.775W$$

$$q_i = 65.135W$$

b.) Find the rate of heat transfer from the fluorescent bulb:
The fluorescent bulb generates seventy percent less heat than the incandescent bulb:

$$q_f = 0.30q_i$$

$$q_f = (0.30)(65.135W)$$

$$q_f = 19.54W$$

c.) Why fluorescent lighting is preferred to incandescent lighting from an environmental perspective:

- Fluorescent bulbs provide more efficient lighting while using up to seventy-five percent less energy than standard incandescent light.
- Fluorescent bulbs prevent millions of pounds of greenhouse gas (carbon dioxide) from entering the atmosphere each year.

- One Energy Star qualified fluorescent bulb can reduce greenhouse gas emissions by more than 500lbs. over its lifetime. This is the equivalent to saving 445lbs. of coal from being burned to generate electricity.
- Fluorescent bulb products generate seventy percent less heat than standard incandescent lighting, which means they are safe, cool to the touch and help reduce household cooling costs.
- Although fluorescent bulbs are more expensive when they are originally purchased, they last much longer than the incandescent bulbs. As a result, they eventually end up saving the consumer money.

Presentation of Green Engineering Problems and Quantifying Green Engineering IQ

For this study, the concept of a greened heat transfer course was received with a mixed response (at best) from the junior chemical engineering class when it was presented to them at the beginning of the semester. The discussion began with an explanation of the concept of "Green Engineering". The students were told that they would be part of a semester long study to determine whether or not the green engineering concepts so enthusiastically embraced by academics could be successfully transferred to students and internalized by students so that these concepts might actually have an impact on industry upon graduation of the students. The students were told how important the concept of green engineering was viewed by such influential agencies as the EPA and about the large number of funded projects that addressed the single issue of green engineering. In spite of all this bravado, the predominant response from the class was "you're trying to make us environmental engineers". Indeed, the initial response from the class was so lackluster, and at times belligerent, that it required a rewriting of the course syllabus so that a specific percentage of the final grade was allocated towards green engineering. From the instructor's point of view, it would have been easy to return to the status quo for the course at this point. However, such a significant amount of time and money had already been invested in the development of the greened problem sets (with similar slotted for the future) that it was necessary to quantify the "transferability" of the enthusiasm and interest of the faculty in green engineering to the students.

At the beginning of the semester, each student was given a two-sided handout that was to be handed in with each homework assignment during the semester and also at the end of the semester with the final exam. One side of the handout stated a widely used definition of green engineering and the student was asked to rate their own green engineering IQ, from 0-10, based on this definition.[1, 4] This handout is seen in Figure 2. The student also used this same sheet to rate their green engineering IQ at the end of the semester.

NAME_______________________________________

On Wednesday, September 22, 2004, on a scale of 0-10 (0 = completely unaware, 10 = completely aware) I give the following statement a rating of:

I understand the mechanisms that determine how chemicals are transported and transformed in the environment and what their environmental and human health impacts are, and how it is possible to incorporate environmental objectives into the design of chemical processes and products – with respect to heat transfer.

0	1	2	3	4	5	6	7	8	9	10

Figure 2. Quantification of Student's Green engineering IQ

The second side of the handout asked the student to rate each individual green heat transfer problem as it was presented to them over the course of the semester with respect to how it impacted (if at all) their green engineering IQ. It is seen in Figure 3.

Please rate the following homework problems (on a scale of 0-10) as to how they helped <u>increase</u> your awareness of how heat transfer design and its related applications impact the environment.

Chapter	**Problem**	**Date**	**Rating**										
1	1		0	1	2	3	4	5	6	7	8	9	10
1	2												
2	1												
2	2												
3	1												
13	1												
13	2												

Figure 3. Student Rating of Green engineering Heat Transfer Problems

Student Evaluation of Green Engineering Problems

Over the period of a 14 week semester students were given 8 homework assignments and one week was typically allowed for completion of each assignment. The assignments varied from one problem to five problems in length, depending on the difficulty of each problem and the students completed a total of 27 heat transfer problems over the course of the semester. Of the 27 problems, 11 problems (approximately 40%) were taken from the newly developed greened heat transfer problem set. The remaining 16 more "traditional" problems were taken from a variety of sources – the predominant sources being instructor's notes and "Process Heat Transfer" by Kern.[5] The Incropera and DeWitt text was used as a reference text for the course and greened heat transfer problems were incorporated into the existing course curriculum whenever suitable (as opposed to developing a new course curriculum that revolved around the greened heat transfer problems).

Of the 27 students in the class, 26 students successfully completed the greened heat transfer problem evaluation. The results were tabulated and the average rating for each problem is shown in Figure 5. The standard deviation of these ratings varied from 1.6 to 2.7.

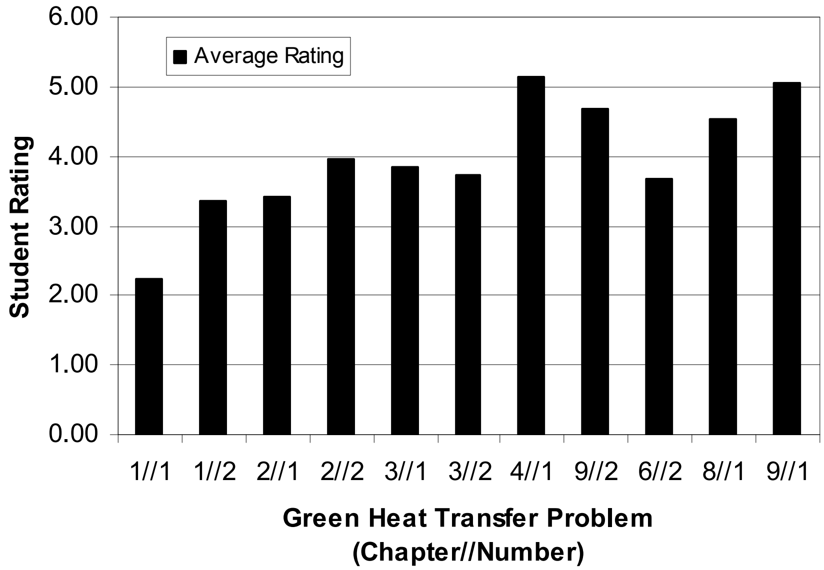


Figure 5. Average Student Rating of Each Greened Heat Transfer Problem Distributed to Students over a One Semester Period

The results from Figure 5 combined with student comments submitted in the green engineering analyses at the end of the semester show that the ratings of the green engineering problems tended to increase as the semester progressed *not* because the students were warming to the concept of green engineering, but rather because they simply *liked* the problems that were presented at the end of the semester better. For example, greened problems in early Incropera and DeWitt chapters tended to be very general and introductory in nature. Problem titles included: Green Engineering Responsibilities (Ave Rating = 2.2), Energy Savings and Environmental Awareness (Ave Rating = 3.3), Proper Disposal of Spent Fuel (Ave Rating = 3.4). Student responses to these early problems in the green engineering analyses included: “waste of time”, “only common sense”, “busy work”. The difficulty arose in the fact that early on in the semester, the students had little in the way of heat transfer design capability and the greened heat transfer problems tended to be qualitative in nature out of necessity. Overall, the ratings for the early greened problems were low and the comments were relatively negative.

In contrast, the numerical ratings given to the problems that were distributed to the students towards the end of the semester were slightly. In addition, these same problems received extremely positive comments in the green engineering analyses. For example, of the 27 students that submitted a green engineering analysis, 27/27 cited the “Rainforest” problem (Ave Rating = 5.1) as a favorite and 23/27 cited the “Argon-Filled Windows” as a favorite (Ave Rating = 4.7).

Sample student comments included: "inspiring", "why can't all homework problems be like this", "changed the way I think about green engineering", "made me think I can make a difference".

Students' Green engineering IQ

As previously stated, 27 students were asked to quantify their green engineering IQ, both at the beginning of the semester and at the end of the 14-week semester. This was done in order to determine if the greened heat transfer problem set had any impact on their environmental awareness and the concept of green engineering. Of the 27 students in the class, only 25 students successfully completed the green engineering IQ evaluation. The results of the evaluation are shown in Table 1.

Table 1. Impact of Greened Heat Transfer Problems on Students' Green Engineering IQ

Student	Green engineering IQ			
	Start of Semester	End of Semester	Rating Increase	% Increase
1	2	5	3	150
2	1	5	4	400
3	4	6	2	50
4	5	9	4	80
5	1	7	6	600
6	1	3	2	200
7	4	8	4	100
8	1	4	3	300
9	1	4	3	300
10	1	3	2	200
11	4	9	5	125
12	4	10	6	150
13	1	9	8	800
14	2	10	8	400
15	3	8	5	167
16	6	8	2	33
17	2	6	4	200
18	3	6	3	100
19	3	7	4	133
20	2	7	5	250
21	3	5	2	67
22	5	9	4	80
23	5	8	3	60
24	8	9	1	13
25	2	6	4	200
Average	**3.0**	**6.8**	**3.9**	**206**

The results show that the average green engineering IQ of 25 students increased from 3.0 at the beginning of the semester to 6.8 by the end of the semester, and equaled 3.9 points on average for each student. In other words, the green engineering IQ of each student increased approximately 200% over the course of a 14 week semester as a result of being exposed to 11 different homework problems that contained a variety of green engineering concepts.

Course Assessment and Modification

The Accreditation Board for Engineering and Technology (ABET) has in recent years placed an emphasis on the concept of a continuous feed-back loop for engineering and technology courses. It is a closed loop process with the goal of successfully achieving the course objectives for a course by continuous evaluation and modification of the course over time. A model similar to that found in ABET was used in this study. The feed-back loop for this work is outlined in Figure 6.

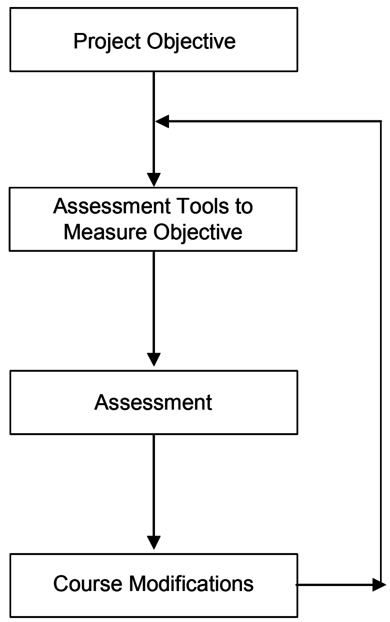


Figure 6. Feedback Loop to Evaluate the Incorporation of Green engineering Concepts into a Design Oriented Heat Transfer Course for Chemical Engineers

The short-term objective of this study was to determine whether or not the awareness of chemical engineering students of green engineering was increased by incorporating green engineering concepts into heat transfer homework problems. This objective is directed towards achieving the overall, long-term goal of enticing chemical engineering students to bring an increased awareness of green engineering concepts into industry upon graduation. The extent to which this objective was successfully achieved is outlined in Table 2.

Table 2. Assessment and Course Modification Analysis

Assessment Tool	Assessment	Course Modifications
Student rating of greened heat transfer problems with respect to how the problem increased their green engineering IQ	The average ratings for the problems from early chapters (1, 2, 3) were lower than the problems from later chapters (4, 6, 8, 9).	Eliminate the problems from early chapters in the future. Multiple assessment tools showed that the students found them too general and ineffective towards achieving the project objectives.
	Even though some of the later chapters received ratings of 8 or 9 from individual students, none of the combined average rating for any one problem was greater than 5.5	Refine the rating system. It may be naive to expect the majority of students to "like" anything about homework. Also, there was too much resolution in the rating system as well as each student having a different point of reference. The rating system should be more qualitative and less quantitative. For example, once the project objective has been given to the student, he/she should simply rate the problem as to whether it was either *effective* or *ineffective* towards achieving that objective.
The rating of the students green engineering IQ at the beginning of the semester and at the end of the semester after the students had been exposed to greened homework problems.	The green engineering IQ of the students went up an average of 3.9 points or approximately 200% over the course of the semester.	The green engineering IQ rating system was a success and a useful tool to determine how much the student themselves felt that their awareness of green engineering concepts had increased. It should be included in the course in the future. Unlike the homework problem rating system, the IQ rating system worked well in this situation because the most important metric was the change in IQ.
Green engineering analysis submitted by each student at the end of the semester.	Of the 27 students that submitted a report, 26 described the experience of being exposed to green engineering concepts in a positive manner. One student agreed that the exposure to greened heat transfer problems increased his awareness of green engineering concepts but he, however, found the knowledge useless.	This was a less quantitative tool than the previous two numerical rating tools and therefore less concrete when using it as a tool to make modifications to the course. However, in many cases it offered the students an opportunity to express themselves other than by assigning a value to their thoughts. In many cases, the students were clearly inspired by the concept of green engineering and were quite eloquent in expressing their thoughts. This was a useful motivational tool for the instructor going forward.
	Many students commented that some of the heat exchanger design calculations in the greened heat transfer problems did not always correlate well with the	Based on the inconsistent correlation between the course notes and greened heat transfer problem, a course modification was made mid-way

	material taught in class, partly because Incropera & DeWitt was not the primary textbook for the course. This was verbalized by the students during the semester and repeated in the end-of-semester analysis.	through the semester. When the students were provided the greened heat transfer problems they were also provided the solutions to the design part of the problem (only). The students were then only responsible for the parts of the problem that pertained to green engineering. This allowed them to focus more, the students were happier and the homework grades increased. This approach should be used in the future if the I&D text is not the primary textbook for the course.
	Many students commented that they would like to spend more time in class in a "round-table" format discussing the solutions to the green engineering section of the problems. They also commented that they would like an entire course devoted solely to green Chemical Engineering (and made the distinction between such a course and an environmental engineering course)	The instructor will make a conscious effort in the future to provide discussion time for the green engineering solutions. The green engineering analysis counted as 5% towards the final grade. This seemed to minimize the number of students who simply wrote what they *thought* the instructor might want to hear or students who simply "mailed it in". It should be given equal consideration in the future if included in the course.
Course Objectives Survey: Objective 8: *To develop an awareness of the concept of green engineering, to become aware of the impact that heat transfer and heat exchanger design can have on the environment*	20/26 (77%) of the students rated this course objective as either 'excellent' or 'good' with respect to how the objective was met. 4/26 (15%) said that this objective was met 'adequately' and 2/26 (8%) said that this objective was met 'poorly'.	Achievement of this course object was a success since 24/26 (92%) students were satisfied with the outcome. However, the course objective was developed at the beginning of the semester and the second part of the statement was too specific and far-reaching with respect to heat exchanger design. In the future it should include only: *To develop an awareness of the concept of green engineering*.

Conclusions

Based on the results of the assessment outlined in Table 2, specifically the green engineering IQ, the green engineering analysis, and the Course Objectives Survey, the objective of increasing the awareness of chemical engineering students to green engineering concepts was successfully achieved. In addition, the success of the project was further punctuated by the fact that 3 students in the course approached the instructor of the course to find out how they could get further involved in green engineering. One student indicated that she would like to spend time doing research on projects that have a green engineering component. The two others expressed a desire to one day own their own Consulting Firm that specialized in green engineering. That wanted to know how they could get more involved in other greened chemical engineering courses. Note should be taken that all three students were specific in their distinction between becoming more involved in greened chemical engineering courses as opposed to environmental engineering courses.

It appears only fitting that this paper should conclude with words from the students involved in the project - since the students (and their words) are a source of inspiration for all who teach.

"There are those within society who must carry a greater burden; those who have the intelligence, knowledge and ability to destroy the world, and those who see the truth. While wisdom requires intelligence, intelligence does not imply wisdom, and wisdom often trails far behind knowledge. Green engineering is an attempt to combine these powerful attributes, and should be embraced by society."
Paul B.

"The Green engineering problems this semester helped students to learn a new method of thinking. In the past many students assumed that operating with concern for the environment meant sacrificing profit and eating a lot of granola. The problems helped show students that operating with environmental issues in mind can be beneficial in many ways, not just for trees."
Nicole A.

"I learned to not always think with my wallet but rather the health of myself, others, and the environment. Overall, I no longer see these assignments as a waste of time or busy work, because of the impact it had on my sense of ethics in the engineering world"
Alex S.

"The purpose of this particular problem was to show that there are situations where the best approach economically is not the best approach environmentally"
Robert P.

"In my own experience with solving these problems I feel that I have gained a greater knowledge of what indeed green engineering is, and they have influenced me to pursue a career in the green engineering field."
Sean H.

"Most of the problems involved weighing the importance of one issue against another, such as deciding whether the money saved, or the economics of the problem, are worth the environmental impact that arises when a certain process is carried out."
Michael B.

"Pollution exists in many forms and avenues of which people are ignorant. The green problems counteract this general lack of knowledge by introducing real-life situations in which the environment is involved. When considering the problems concerning the environment, ignorance is the greatest problem and knowledge is the greatest weapon."
Naveen K.

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