Teaching Teachers to Teach Green Engineering

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Abstract

The work provides guidelines for instructors who wish to incorporate green engineering concepts into a typical non-green engineering course without diluting course content or modifying the course syllabus by identifying 5 critical elements necessary to the successful integration of green engineering concepts into any traditional, design-oriented, non-green engineering course. The 5 critical elements result from the assessment of the incorporation of green engineering concepts into a traditional, design and analysis oriented heat transfer course offered to chemical engineering students in the fall semester of their junior year. This work not only incorporates the instructor's assessment of the newly greened course but also assessment of the same course by a student task force. This work includes portions of the instructor's assessment, the student task force's independent assessment of the course as well as the task force's assessment of the instructor's proposed modifications to the course. Even though this study focuses on green engineering as it relates to heat transfer, the assessment and suggestions are relevant to all non-green engineering courses that attempt to integrate green engineering topics.

Keywords: Green Engineering, assessment, heat transfer, design

Introduction

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] More specifically, green engineering has been described as the incorporation of nine specific "San Destin" principles into engineering practices.[3, 4, 5] The San Destin Green Engineering Principles are as follows:

1. Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools.
2. Conserve and improve natural ecosystems while protecting human health and well-being.
3. Use life cycle thinking in all engineering activities.
4. Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible.
5. Minimize depletion of natural resources.
6. Strive to prevent waste.
7. Develop and apply engineering solutions, being cognizant of local geography, aspirations and cultures.
8. Create engineering solutions beyond current or dominant technologies; improve, innovate and invent (technologies) to achieve sustainability.
9. Actively engage communities and stakeholders in development of engineering solutions.

Following in the footsteps of Hesketh et al., the goal of this work is to provide guidance for instructors who want to integrate green engineering concepts into a design-oriented engineering curriculum – as opposed to offering environmental engineering electives to engineering students in their senior year, leaving students with the impression that environmentally conscious engineering is an "add-on" or an afterthought.[5] Hesketh states that " one of the precepts of green engineering is that it should be conducted at all levels of engineering practice and design, …and that it should be taught at all levels." This work attempts to show how that theory was implemented as well as quantify the success of that implementation via detailed assessment.

Typically, in an effort to improve their courses, instructors re-evaluate their curriculum based on assessment that is derived predominantly from student surveys. This work not only incorporates the standard instructor's assessment of the newly greened course but also assessment of the same course by a student task force. The task force was comprised of three undergraduate students who had successfully completed the greened course and who had expressed a desire for additional green courses to be added to the undergraduate, chemical engineering curriculum. This paper includes a few key portions of the instructor's assessment of the newly greened engineering course, the student task force assessment of the instructor's proposed modifications to the course for when the course is taught again, and the student task force's proposal as to how green engineering could be presented more effectively in the future. A complete, in-depth assessment by the instructor of the greened course is presented elsewhere.[6, 7]

The assessment of this course may be described as a closed, continuous feed-back loop similar to the assessment process outlined by the Accreditation Board for Engineering and Technology (ABET). The assessment feed-back loop for this work is seen in Figure 1.

Background

An effort was made to integrate green engineering concepts into a predominantly design and analysis oriented, chemical engineering heat transfer course offered in the fall semester of the student's junior year. One of the goals of the course is to prepare students for a one-year plant design course in their senior year. Typical course objectives include development of convective and overall heat transfer coefficients as well as design of double pipe, shell and tube, and extended surface exchangers. The class was a 3-credit, 14-week course that met for 55 minutes, three times per week and did not include a laboratory component. The class was comprised of 27 students in total, 9 (33%) females and 18 (66%) males. The textbook used for the course was *Heat Transfer - A Practical Approach* by Yunus A. Cengel.[8] The incorporation of green engineering concepts into the course was predominantly through green heat transfer homework problems that had been developed previously. A detailed analysis of some of the more popular problems is also presented elsewhere.[9, 10]

The homework problems consisted of two parts. Part I of each problem addressed key heat transfer design concepts such as conduction and convection resistance as well as standard heat exchanger design elements that are typically part of any heat transfer design course. Part II of each problem then addressed key green engineering issues by examining the impact of that design on a specific environment. The greened heat transfer problem set included a total of 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 key green engineering concepts outlined in *Green Engineering – Environmentally Conscious Design of Chemical Processes* by Allen and Shonnard.[11, 12] The entire problem set with solutions as well as a greened heat transfer semester project may be found at www.rowan.edu/greenengineering. A sample of some of the homework problems as well as a synopsis of the semester project are presented below to illustrate how green engineering concepts were incorporated into the heat transfer design course.

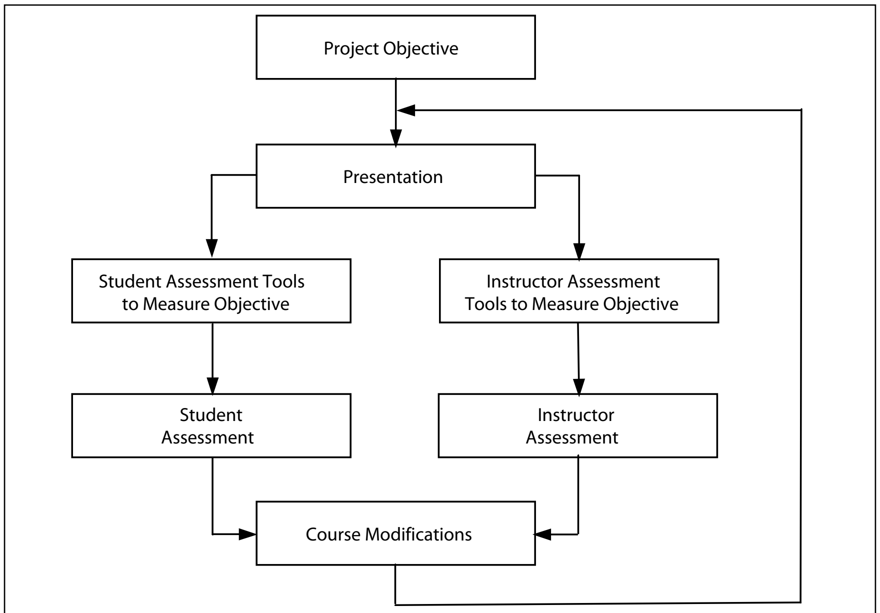

Figure 1. Feedback Loop to Evaluate the Incorporation of Green Engineering Concepts into a Design Oriented Heat Transfer Course

Energy Efficient Lighting

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 converts only a small amount of the electrical energy into light; the rest is converted to heat. In spite of this inefficient conversion of energy, the relatively inexpensive purchase price of incandescent bulbs when compared to fluorescent lighting accounts for their popularity amongst consumers.

When analyzing this problem, students found the following:

- the rate of heat transfer from a typical 75W incandescent bulb was approximately 65W compared to 20W from the fluorescent bulb – a reduction of approximately 70%.
- not only was the fluorescent bulb more efficient in converting electrical energy to light, but one Energy Star qualified fluorescent bulb could reduce greenhouse gas emissions by more than 500lbs. over its lifetime (which is equivalent to saving 445lbs. of coal from being burned to generate electricity).
- even though the fluorescent bulb was more expensive than the incandescent bulb, it had a significantly longer lifespan than the incandescent bulb. The lifespan of each bulb varied from manufacturer to manufacturer but a 75W incandescent bulb averaged 750 hours and a 75W fluorescent bulb averaged 10,000 hours.
- a cost analysis showed that the total light bulb cost for a typical home decreased by approximately 53% over a five year period when fluorescent bulbs were used in place of incandescent bulbs.

Natural Convection Through Windows

Many homeowners, when faced with the replacement of their old, single-pane wood windows, have difficulty choosing a replacement window. Students were required to compare the replacement of 25 single-pane windows with either standard (air filled) double-pane windows at a cost of approximately $325 each or argon-filled double-pane windows at a cost of approximately $400 each.

The student discovers the following when analyzing the problem:

- the trade-off between the reduction in heat loss when choosing the argon-filled replacement window (the heat loss is reduced by approximately 35% when choosing the argon-filled replacement windows (33W) over the air-filled replacement windows (51W)) and the initial capital investment (the air filled windows are approximately 25% more expensive than the argon-filled windows).
- the energy reduction translates to a total savings of approximately $25,000 for the air-filled windows and approximately $68,000 for the argon-filled windows over a 25 year period.

Optimization of a Heated Swimming Pool

Students were required to optimize the heating of an in-ground swimming pool by incorporating three San Destin Green Engineering Principles. The students were required to find the optimum time of day to turn on a pool heater so as to maximize the comfort of the swimmer while minimizing energy consumption.

When solving this problem, students found the following:

- a family of solutions that accounted for variation in air temperature over a 24 hour period, wind conditions, and a user specified set point for the desired pool temperature.
- experimentation with the model showed that energy consumption could vary by as much as 40% for a given set of specifications, depending on the time of day when the heater was turned on.

Over the entire 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. The students completed a total of 27 heat transfer problems. Of the 27 problems, 11 problems (approximately 40%) were taken from the previously described greened heat transfer problem set. The remaining 16 traditional problems were taken from a variety of sources – the predominant sources being instructor's notes and Process Heat Transfer by Kern.[13]

The presentation of the newly greened course began with a very brief introduction to green engineering by the instructor and the students were each asked to rate their own green engineering IQ on a scale of 0-10. The green engineering IQ was developed by the instructor to attempt to quantitatively gauge the depth of a student's understanding of green engineering concepts.[6, 7] The instructor outlined the growing importance of green engineering and its increased prominence in many influential government organizations and industry.

As previously noted, green engineering problems were assigned in conjunction with traditional design-oriented homework problems during the semester. Initially, the green problems were assigned to the class in their entirety during the first half of the semester, i.e., the students were required to solve the part I design component as well as the part II green engineering component of each problem. However, the design component of the greened problem set did not always correlate well with the course schedule. Therefore, during the second half of the semester, it was necessary for the instructor to provide solutions to part I of each problem so that the students could focus primarily on part II (green engineering). Each student was also required to rate each green engineering problem from 0-10 with respect to how it impacted (if at all) his or her green engineering IQ. The student's numerical rating of each problem was turned in to the instructor with each homework assignment, recorded, and returned to the student with the graded homework.[6, 7]

Finally, at the end of the semester, each student was required to rate their green engineering IQ for a second time. The change (if any) in the student's green IQ was used as an assessment tool by the instructor to determine if the green homework problems were an effective method of introducing green concepts into a design-oriented engineering course. The students were also required to submit an two-page analysis of how their awareness of green engineering concepts had been affected over the course of the semester as well as site specific examples of which green problems had had the most significant impact (positive or negative). The green analysis was originally presented as a homework assignment but was increased in value to 5% of the student's final grade so as to emphasize the importance of the awareness of green engineering in a design curriculum.

Assessment

The assessment of the greened heat transfer course was performed in two separate phases.

Phase I

Phase I consisted primarily of the instructor's assessment of the greened course. The assessment was performed immediately upon completion of the course at the end of the semester. A compilation of the assessment tools, the instructor's assessment and the instructor's proposed improvements to the greened course can be seen in Table 1, columns 1-3. Note should be taken that last column in Table 1 is the student task force's assessment of the instructor's observations and will be discussed in greater detail later. A brief description of each assessment tool used by the instructor and later by the task force is as follows:

1. The student's rating of their own green engineering IQ at the beginning as well as at the end semester.

Students were asked to rate their awareness of the following statement on a scale of 0-10: "I understand the mechanisms that determine how chemicals are transported and transformed in the environment, what their environmental and human health impact are, and how it is possible to incorporate environmental objectives into the design of chemical processes and products with respect to heat transfer". A rating of 0 implied that the student had little understanding of the above statement while a rating of 10 implied that the student had a strong understanding. The results showed that the average rating of all students' green engineering IQ at the beginning of the semester was 3.0/10. However, by the end of the 14 week semester, the students themselves felt that their awareness of green engineering concepts had increased by more than doubled to 6.8/10.

2. The student rating of each green engineering problem as to how it impacted their awareness of green engineering concepts.

Upon completion of each green problem, each student was asked to rate each problem on a scale of 0-10. A problem with a rating of 0 implied that the problem did little to further the concepts of green engineering while a problem with a rating of 10 was considered a very effective tool for highlighting green engineering concepts. The results for all green engineering problems were compiled and are seen in Figure 2.[6, 7]

The results from Figure 2 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. Student responses to these early problems in the green engineering analyses included: "waste of time", "only common sense", "busy work". 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 rated slightly higher combined with extremely positive comments submitted in the green engineering analyses. Sample student comments to the later problems 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".

The green engineering course analysis submitted by each student at the end of the semester.

Each student was required to submit a written analysis (two-page minimum) as to what part of the course impacted their green engineering awareness and additionally, how it was impacted. Students were required to site specific examples. This tool offered the students the opportunity to share any additional thoughts that had not been covered by the student surveys. Not only was this an extremely useful tool for the instructor, but an inspiring one also.

3. The course objectives survey.

As part of a typical course objective survey presented to students at the end of a semester, students were asked to rate how effectively the following course objective was met: "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". The students

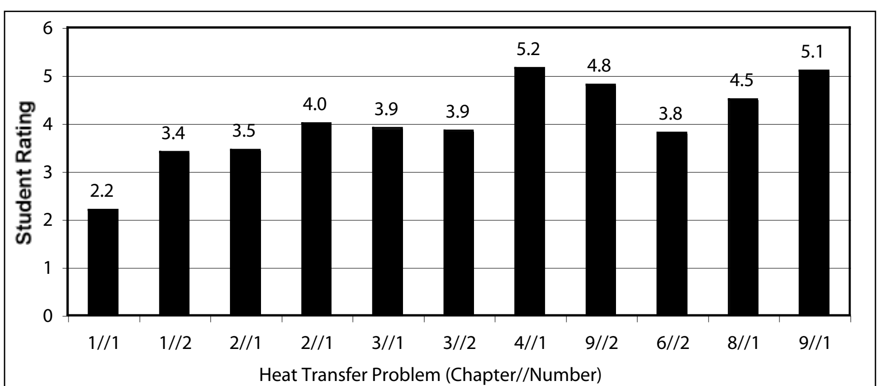

Figure 2. Average Student Rating of Each Greened Heat Transfer Problem Distributed to Students over a One-Semester Period – Listed by Chapter and Problem Number

were provided with the following rating system: excellent; good; adequate; poor. Of the 26 students that completed the survey, 20/26 (77%) rated this course objective as either 'excellent' or 'good' with respect to how the objective was met.

Phase II

Phase II consisted primarily of the student task force's assessment of the greened heat transfer course. Unlike the instructor's assessment of the greened course, the task force's assessment was performed during the semester following the semester that the greened heat transfer course was taught. Brief descriptions of the tools used by the student task force are as follows:

1. Student Survey Developed by the Student Task Force.
   Section I: Homework Assessment
   Section II: Topics for Future Homework Problems
   Section III: Classroom Discussion and Suggestions for Course Improvement
2. Student Forum
3. Student Task Force Assessment of Instructor's Proposed Modifications to Greened Course.

Task Force's Student Survey

As previously described, the survey distributed by the task force was organized into three sections and was developed to further assess the newly greened curriculum. The survey was given approximately two months after the heat transfer course had ended. This provided students with ample time to reflect and internalize the green engineering topics presented in the previous semester's course. The survey was completed by 22 of the 27 students that had taken the heat transfer course the previous semester.

Student Survey: Section I – Homework Assessment

Since the primary vehicle for incorporating green engineering concepts into the course was via homework assignments, assessment of this part of the course was critical. The task force assessed the manner in which homework was presented as well as the manner in which solutions were discussed.

During the first half of the semester, students were required to complete the design portion (part I) as well as the green engineering portion (part II) of each greened homework problem. This format proved difficult for the students as the design content of the greened heat transfer problems was based on the Fundamentals of Heat and Mass Transfer by Incropera and DeWitt (I&D) which was used as a reference rather than the primary textbook.[11] While the design concepts were consistent between the primary textbook for the course, Cengel, and the reference textbooks Kern and I&D, often the nomenclature or the approach to problem solving were not.[8, 11, 13] After a mid-term assessment of the format of the greened homework assignments, the instructor decided to provide the students with the solution to the part I portion of each greened heat transfer problem so that the students could use those results to develop solutions to the green engineering questions in part II. This proved to be very effective as the students were able to devote more time to understanding and absorbing the green engineering concepts. Finally, the student task force examined the amount of time spent discussing the solutions that students had developed to the green engineering questions. Typically, the major portion of the class time was spent on reviewing the traditional design problems that had been assigned for homework – many of which amounted to mini-projects. As a result, only a minor amount of time was available for discussion of green concepts.

The task force asked the students to rate how each of these issues impacted their awareness and understanding of green engineering concepts, i.e., their green engineering IQ. The following issues were rated on a scale of 1 to 5: students being responsible for the solution to part I and part II of each green problem; students being responsible for part II only of each green problem; and classroom discussion of solutions to green engineering questions. A rating of 1 implied that it contributed minimally to the student's awareness of green engineering concepts while a rating of 5 implied that it was significant. The results are seen in Figure 3.

Two main conclusions were drawn by the student task force upon evaluation of the previous results. First, the student task force found that the manner in which homework problems were presented during the first half of the semester had less impact on the student's awareness of green engineering concepts (2.9/5.0) as compared to the manner in which the problems were presented during the second half of the semester (3.4/5.0). Discussion with the students found that they had to spend too much time navigating the solutions to the part I portion of the green problems and that they found it awkward shifting between different problem solving approaches and nomenclature. When the solution was provided to the part I portion of the problem, the students actually enjoyed investigating the green engineering solutions. Therefore, it is the suggestion of the student task force that the green engineering heat transfer problems should be used in their entirety when the textbook on which they were based, Incropera and DeWitt, is used as the primary textbook for the class. Otherwise, the students should be allowed to focus solely on the green engineering concepts found in part II of each problem.

The second conclusion drawn by the task force was that even though the amount of class time devoted to discussion of green engineering solutions was brief, it was found to have significant impact on the green engineering IQ of the students. The discussion component received the highest rating of the three: 3.5 on the 5-point scale. In addition, it will be shown later that almost 80% of the students who participated in the student forum expressed a desire for significantly more time devoted to classroom discussion of green engineering homework solutions.

Student Survey: Section II –Topics for Future Homework Problems

The goal of the task force was to identify topics for green engineering homework problems that the students would find interesting in the hope that more interesting topics would facilitate the awareness and interest in green engineering concepts. The students were asked to rate a variety of broad topics on a scale of 1 to 5. A rating of 1 implied the students had little interest in the topic while a rating of 5 implied the greatest interest. The five topics developed by the student task force from which homework problems could be developed are provided below:

1. The Home - problems focusing on the home lighting could include a comparison of the energy saved (or wasted) by a fluorescent light bulb compared to an incandescent light bulb or the energy saved (or wasted) in a home as a function of the type of insulation and windows used.
2. World Issues – an example of world issues from which an assignment could be drawn is the design of an oil pipeline that passes through a delicate environment such as a rainforest. The students could be asked to investigate the positive (economic) and negative (health and environmental) impacts on the surrounding areas.
3. Regional Issues – in every region throughout the world there are unique environmental issues that students from that area can relate to and these issues provide a multitude of topics from which homework problems could be derived. For example, students from the Northeast could be assigned homework problems focusing on issues that include pollution in the Hudson River, the "dead" lakes in the Adirondacks due to acid rain, and the Love Canal disaster.
4. Industrial Issues – many industries today are faced with a variety of green engineering problems. For example, many companies are now required to use a specific portion of green tag energy. A homework assignment could require students to investigate ways in which to increase the amount of green tag energy consumed.
5. Traditional Classroom Design Problems – such problems include the design of heat transfer coefficients and a variety of heat exchangers to cool or heat different process fluids. The green engineering section of each problem could be the analysis of the environmental impact of that design.

The results from the student survey examining interesting topics for green engineering problems can be found in Figure 4.

Based on an analysis of the data collected from the student survey, the student task force determined that the topics of most interest to the students were those concerning world and industrial issues and that green homework problems developed from these areas would have the greatest impact on increasing the

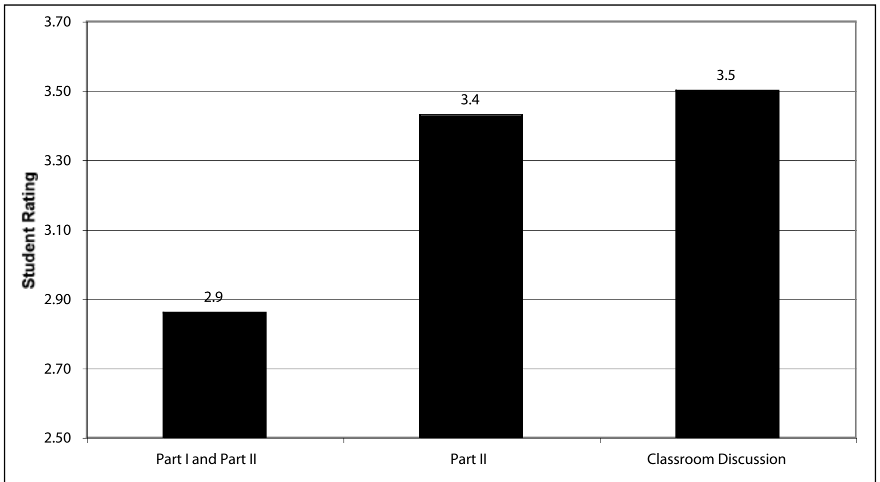

Figure 3. Average Student Rating of How Three Different Components in a Greened Heat Transfer Course Impacted the Student's Green Engineering IQ.

student's awareness of green engineering concepts. The topics in order from most effective to least effective are world issues, industrial based problems, home based problems, and regional issues. The traditional design problems received the lowest rating of the five categories indicating that they would probably be the least effective when attempting to spark the student's interest in green engineering issues.

Student Survey: Section III – Classroom Discussion and Suggestions for Course Improvement

The third and final section of the survey consisted of two short-answer questions. First, the students were asked if they would find a classroom discussion dedicated to green engineering topics beneficial to increasing their green engineering IQ. The second question was open ended and asked students for one suggestion to improve the integration of green engineering concepts into the previously taught design-oriented heat transfer course. The two questions were as follows:

1. "Would you find a classroom discussion once per month on green engineering homework problems and concepts beneficial to your understanding of green engineering?"
2. "If you could make one change to the green portion of the heat transfer curriculum as it was presented the previous semester, what would it be?"

The results of the first short answer questions are provided in Figure 5[7].

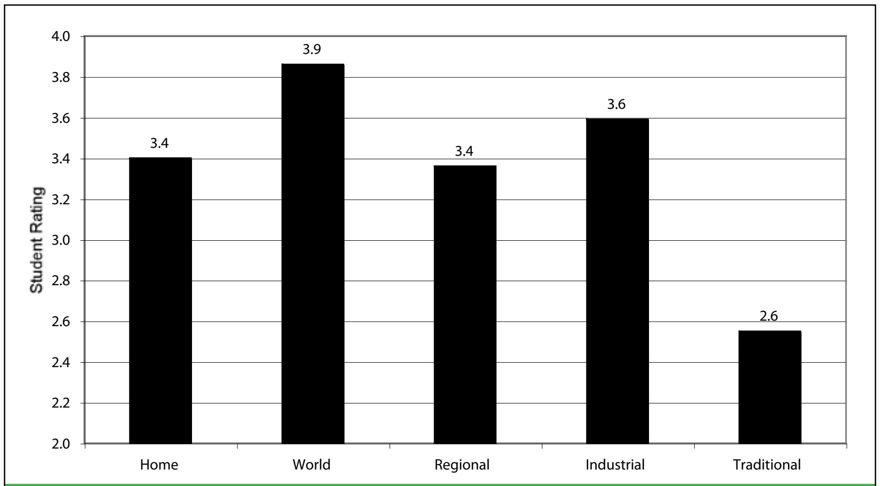

Figure 4. Average Student Rating of Varying Homework Topics Presented in Section II of the Green Engineering Survey

Significantly, 82% of the 22 students who completed the survey responded that setting aside one class period per month for discussion of solutions to green engineering problems would be beneficial to their green IQ, and only 9% responded that it would not be beneficial. The students indicated that a free-form, round-table discussion would be most desirable. Based on the overwhelming support by students for this type of discussion, the student task force concluded significant in-class discussion is essential to a greened curriculum.

The suggestions provided by the students in the open-ended question of the survey were so varied that the task force decided that a student forum would be necessary to discuss, explore, clarify and quantify the issues further.

Student Forum

The student task force received such a wide variety of responses to the open-ended question on the student survey that they felt it was necessary to hold a student forum to discuss the issues further. The task force decided upon a one-hour forum that was held 3 months after the greened heat transfer course was taught. The forum was run entirely by the student task force and the instructor was not present. Participation in the forum was completely voluntary. However, 100% (24) of the students who had successfully completed the greened heat transfer class the previous semester and were still at Manhattan College attended the forum. The student task force opened the forum by asking specific questions such as, "Why do you think discussion of greened homework problems and green concepts would be helpful?" The task force then asked students to volunteer their own suggestions as to how to improve the presentation of green engineering material. After each suggestion was made, other students were asked for their comments and then the entire class was asked to show their

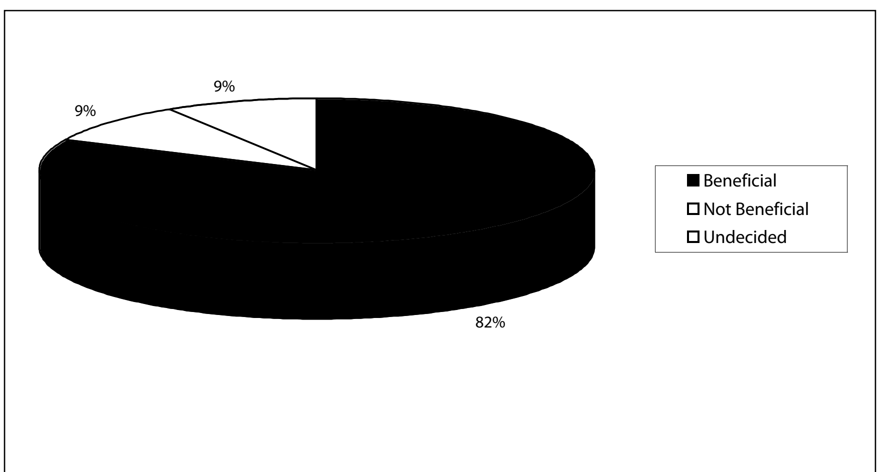

Figure 5. Student Rating of Classroom Discussion as Being Either Beneficial or Not Beneficial to Improving Their Green Engineering IQ

support for implementing these suggestions by a show of hands. This technique was used to quantify the information presented during the forum. The student task force was amazed at the number of suggestions presented by the class as well as the level of interest shown by the class – especially since such a long time had passed since the course was taught. In addition, it should be noted that the suggestions presented by this group of students would not be benefiting themselves, but rather the class that followed them. A compilation of the suggestions that received the most support can be seen in Table 2.

The suggestion to use online discussion forums had minimal support among students; only 50% of the class was in favor. In contrast, the inclusion of an introductory text in the curriculum had complete support of the students and they felt that it would be an absolute necessity to any green course in the future. The Allen and Shonnard text was offered as a possible solution. However, the students thought it is too expensive to be used as a reference text (approximately $79) and too comprehensive for a quick read. Surprisingly, 96% of the class wanted to be tested on the green engineering material, either through quizzes or through the addition of a green engineering problem to their regularly scheduled exams. Student desire to include discussion in the curriculum appeared in two forms: incorporating a significant amount of class discussion into the schedule and a group research project at the end of the semester. Both of these suggestions were supported by at least 79% of the class. Students also supported modifying the homework problems to make them more industrially oriented.

Task Force Assessment of Instructor's Proposed Modifications

Once the student task force had assessed the newly greened heat transfer course utilizing their own assessment tools they decided the next step was to assess the instructor's proposed modifications prior to making their own suggestions as to how to better integrate green engineering into a traditionally design-oriented course. The task force's assessment of the instructors course modifications can been seen in Table 3.

Assessing the instructors proposed course modifications was critical in the development of the student task force's own proposed course modifications.

Assessment Tool	Student Task Force Assessment	Task Force Suggested Course Modifications
Homework Analysis [6, 7]		
Introduction of green engineering concepts by requiring students to complete design component (part I) as well as green engineering component (part II) of greened heat transfer homework problems.	This methodology received an overall rating of 2.9/5 with respect to how it positively impacted the student's green engineering IQ.	The students should be required to complete the part I portion of the greened problems only if the primary textbook for the course is Incropera & DeWitt.
Introduction of green engineering concepts by providing the students with solutions to part I of each greened homework problem and requiring the students to use the results to answer part II of the greened problems.	This methodology received an overall rating of 3.4/5 with respect to how it positively impacted the student's green engineering IQ.	This methodology should be used if the primary textbook for the course is other than Incropera & DeWitt.
Classroom discussion of green engineering solutions when homework assignments are handed in.	This methodology received an overall rating of 3.5/5 with respect to how it positively impacted the student's green engineering IQ.	More time should be provided to students to share and compare their proposed solutions to green engineering problems.
Green Engineering Topics		
The students were surveyed to find what topics they found interesting that could be incorporated into green engineering problems, and indeed homework problems in general. The students then rated these topics (on a scale of 1-5) to find which were the most interesting.	Problems that dealt with world issues (3.9) and real-life industrial issues (3. 6) received the highest interest ratings. Next highest were problems that dealt with the home (3.4) and problems that were specific to a particular region in the U.S.(3.4). Last on the list was typical design problems (2.6) that are ordinarily presented as homework problems.	Clearly, the students are more interested in assignments that incorporate the course requirements but also issues outside the classroom and are bored with "business as usual". The instructor will need to spend more time developing problems, both for homework and exams that incorporate both.
Short Answer Questions		
The students were asked to respond to the following question, "Would you find a classroom discussion once per month on green engineering homework problems and concepts beneficial to your understanding of green engineering?"	82% of the students responded that classroom discussion would be beneficial.	Even though the course schedule is already packed with material that needs to be covered (with little time to spare), it is clear that if green engineering is going to be incorporated successfully into a design curriculum, significant class time must be set aside for discussion. Otherwise, leave the green engineering concepts out of the course.
The students were asked to respond to the following question, "If you could make one change to the green portion of the heat transfer curriculum as it was presented the previous semester, what would it be?"	The responses were so varied that the task force decided to hold a student forum to address the question further.	

Table 1. Summary of Student Survey Assessment and Course Modification Analysis

The Critical Elements of Teaching Green Engineering

Based on the student survey, the student forum, the instructor's assessment of the previously taught heat transfer course, and the student task force's assessment of the instructor's proposed modifications, the student task force has identified 5 critical elements necessary to the successful integration of green engineering concepts into any traditional, design-oriented, non-green class. The five critical elements are as follows:

1. Provide students with a short, introductory text.
2. Periodically test students on their green engineering knowledge.
3. Include significant classroom discussion before and after homework assignments have been completed.
4. Assign group research projects.
5. Include homework assignments that address world issues and are industry-based.

The first critical element, providing students with an introductory text, emerged as the most important modification to the previously greened heat transfer course that should be made in order to improve the effectiveness of the curriculum. This text is meant as a brief introduction to green engineering. The text could include green engineering principles, real world examples of green engineering dilemmas and possible solutions. A reference list could also be provided that included other texts, Internet sources, and journal articles related to the concepts of green engineering – but they would not be as critical as a concise, introductory text. This would provide an excellent source of information for students during the course of the semester. It is important to note, that this text should not be another formal textbook that students would be required to purchase. Instead this text should be a brief tutorial that provides a concise overview of green engineering material. This text is not meant to be the main teaching tool used by instructors, but rather a source of general information about green engineering for students to reference.

The second critical element identified by the assessment of the task force was to periodically test students on their green engineering knowledge during the course of the semester. One of the main pitfalls of the newly greened curriculum as it was originally presented was that students found it difficult to take such a qualitative subject such as green engineering serious in such a quantitative design-oriented course. Testing this material was found to be an effective way to combat this pitfall. The task force found that if the student's knowledge of the material presented played a significant role in the calculation of their grade, students were much more likely to conscientiously learn the material. By testing the students, the instructor is also communicating the importance of the green engineering material to the class. This testing could be administered in two possible forms. The first form of testing could include short quizzes after several homework assignments have been completed. The quiz would focus on the green engineering material presented in those assignments. The second form of testing could include a question on a regularly scheduled exam worth approximately 10%-15% of the total test grade. The question would be based on the green engineering

Suggested Course Modifications Resulting from Student Forum Discussion	Number of Votes	Percent in Favor	Ranking
TEXT. The students expressed a desire and a need for a very short, introductory text that highlighted the fundamental concepts of green engineering. The students also wanted something that they could refer to from time to time during the semester.	24	100%	1
TESTING. If the students were going to spend time on green homework problems, they also wanted to have test questions based, either partly or entirely, on green engineering concepts.	23	96%	2
Research Project. The students wanted to have the opportunity to work together in a cooperative fashion in a group on a large green engineering project. Ideally, they would like to work on a "real" project supplied by local industry. The students felt that this would also provide an opportunity to discuss potential solutions. The students felt that the ideal length of time for the project would be 4 weeks.	21	88%	3
Classroom Discussion. Many students felt very strongly that it was only discussion of solutions to green engineering problems in class that had a significant impact on their green engineering IQ. The students were interested to find out what other students had come up with. They felt that homework problems without a reasonable amount of discussion were valueless.	19	79%	4
Economic & Environmental Problems. Many students felt that green problems had more of an impact when they had an economic component. They said that their awareness and interest in green engineering grew as the potential to save money increased.	18	75%	5
Online Discussion. As an alternative to in-class discussion, students suggested an on-line discussion. Even though 50 % of the students were in favor of online discussion, the support generated for this was lack-luster at best.	12	50%	6

Table 2. Student Forum Course Modification Analysis

Assessment Tool	Instructor's Assessment	Instructor's Course Modifications[6, 7]	Student Assessment of 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.	Early problems should be eliminated. Student comments confirm that students considered the introductory problems to be a waste of their time and resulted in them losing interest in the topic.
	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 problems should be rated according to the effectiveness or ineffectiveness toward achieving the problem objective. The rating for success will therefore be more qualitative than quantitative. Input from discussion of the problems can also be used to gauge the success of the affect of each homework problem on a student's green engineering IQ.
The rating of the student's 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.	Before asking students to rate their green IQ, the students should be "educated" more fully as to what green engineering is. The students felt that a very short, concise introductory text that highlighted green engineering fundamentals should also be provided.
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.	The written analysis should be kept, but it should be coupled with discussion as classroom discussion provides an indication of the varying intensity that the group feels for each suggestion. A student task force should run these discussions without the instructor present to ensure honesty and foster critically constructive comments.
	Many students commented that some of the heat exchanger design calculations in the greened heat transfer problems did not always correlate well with the 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.	Based on the inconsistent correlation between the course notes and greened heat transfer problem, a course modification was made mid-way 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.	The inconsistency did present a problem for many students. Students should only be responsible for the design portion of the greened problems if the I&D text is 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.	Include a class discussion at least once a month to prepare students to be tested on the material and to allow them to voice their interpretations of the material.
		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.	Continue to count the analyses as a significant portion of the final grade. To maintain the desired level of commitment throughout the semester, include quizzes or small test questions to communicate the importance and seriousness of green engineering.
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*.	The modification suggested by the instructor should be carried out, but only if a text is provided to explain to students what "*an awareness of green engineering*" includes.

Table 3. Student Task Force Assessment of Instructor's Proposed Course Modifications

concepts that were presented in the homework problems and class discussions prior to the exam. Either form of testing could be considered appropriate and effective; the choice depends on which form could be more easily integrated into the instructor's curriculum.

In order to implement testing and to improve the understanding and retention of green engineering material, the task force determined that discussion of green engineering concepts must be included into an instructor's curriculum. Introducing a discussion session initially seems very foreign to a non-green, design course. However, a discussion was identified by the student task force as an essential component of effectively presenting green engineering material to students – predominantly due to the very qualitative nature of green engineering. The student task force suggests devoting one class period per month (approximately 4 classes over a 14-week semester) to the discussion of green engineering. The purpose of this discussion is twofold; to clarify any misunderstanding of the green engineering material covered in the homework assignments and to allow students to share and discuss the solutions they developed while completing the assignments. An essential component to the presentation of green engineering is that students must learn not only from the instructor but also from the thoughts and ideas of their fellow classmates. The discussion also provides instructors with material to develop fair questions for quizzes or exams.

The fourth critical element essential to the effective integration of green engineering into a non-green curriculum was identified as assigning group research projects to students. It is suggested by the student task forces that the projects should be 3-4 weeks in length and are assigned towards the end of the semester as a culmination of the green engineering concepts presented during the course of the semester. The suggested group size would include 2-4 students. Topics for the project could be chosen from a list provided by the instructor. However, if students are interested in researching a topic not found on the list it should be allowed at the discretion of the instructor. An essential component of the group research project could be a 5-7 minute PowerPoint presentation made by each group in front of the class. Attendance to all presentations by all students should be mandatory. As stated above, a critical component to the effective presentation of green material, is that each student should learn be exposed to the thoughts and ideas of their classmates. The research project will allow students to utilize the green engineering knowledge that they gained during the course of the semester to investigate and propose or discuss a solution to a real-life green engineering problem.

The fifth and final critical element for effectively presenting green engineering identified by the student task force is to base homework problems on real world issues. By developing assignments that are based on real world problems faced by industry, students will emerge from the course having a practical working knowledge of green engineering. Emphasizing the importance of green engineering to an industrial world that the students will soon be entering, and will encourage students to treat the material with the same respect that they give to the traditional design material.

Conclusions

Initially, for an instructor, integrating green engineering into a typically non-green curriculum can seem very difficult. Since green engineering is such a unique topic, unique teaching methods foreign to traditional non-green courses must be implemented to effectively present the material to students. The five critical elements derived by the student task force's assessment of the newly greened, design-oriented heat transfer course mentioned above were found to be the most effective methods to presenting the unique subject of green engineering to students.

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