

2015

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Recommended Citation

O'Flaherty M.P., Chance, S, Farrell, C.F., Introducing New Engineering Students to Mechanical Concepts through an “Energy Cube” Project, *International Joint Conference on the Learner in Engineering Education (IJCLEE 2015)*, San Sebastian, Spain, July 6-9, 2015.

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Introducing New Engineering Students to Mechanical Concepts through an “Energy Cube” Project

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Abstract

The objective of this paper is to describe a problem based learning module, called the “Energy Cube”, offered by Dublin Institute of Technology that is designed to teach mechanical, building services and manufacturing engineering concepts to first year engineering students. The Energy Cube project gives students hands-on experience in areas ranging from heat transfer, lighting and energy efficiency to industrial and product design. In the Energy Cube, students design and construct (using cardboard, clear plastic, and glue) a model of a building that admits as much daylight as possible while being energy efficient and aesthetically pleasing. The students, working in teams of four, complete most of the work within six four-hour blocks allotted for the project. Each week, students are given specific goals: (1) generate design specifications, (2) create an evaluation matrix and use it to select two preliminary designs, (3) choose one final design and make detailed construction drawings, (4) construct the final model, (5) test performance of models and record results, (6) submit and present a final report that includes recommendations for improvement. Performance tests determine what percentage of available ambient light reaches the interior and how much heat (generated by an incandescent light bulb) is retained over a 30-minute period. Quality of construction is measured using an air tightness test. The teaching team, comprised of engineering and design educators, assesses aesthetics subjectively. Individual contributions are evaluated using attendance records and peer assessments. Student feedback, via a survey, was positive regarding teamwork and team-building. It also showed a good balance among the diverse learning outcomes.

Keywords: problem based learning; design and build; peer assessment; project based approach; energy engineering.

1 Introduction

This paper is geared toward engineering educators who wish to provide students with hands-on approaches to learning mechanical engineering concepts such as heat transfer. The paper describes the mechanical engineering design project module taken by first year general engineering students in the Dublin Institute of Technology. The module is intended to give the students a broad introduction to concepts and methods used in mechanical, building services, manufacturing and design engineering.

This paper, authored by the lecturers who organized and taught this project in its first year, begins by introducing how the module fits into the broader engineering programme. We describe overarching objectives of the module. Next, we provide a week-by-week description of the module’s content. We explain our methodology for assigning marks and note how this aligns with intended learning outcomes. We then analyse and present feedback from the students regarding their recommendations for change, satisfaction with the assignment, and what they believe they learned.

The overall Engineering Design Projects module, of which this project is a major component, adopts a Problem-Based Learning (PBL) approach. Galand *et. al.* (2012) indicated that PBL can be effective in engineering education, particularly for the application of principles. Chua (2014) found that a hybrid PBL-lecture model produced better performance with first year students. He posited the explanation that “*they may lack the problem-solving and interpersonal skills needed to participate in full-fledge PBL sessions*”. Strobel and van Barneveld (2009) found that PBL proved more effective for long-term retention of knowledge. A study by Yadav, Subedi, Lundeberg, and Bunting (2011) involving 55 electrical engineering students found learning gains among PBL students to be twice those of students in the control group (who were taking traditional lecture courses). The authors felt when devising this module that the enhanced student interaction and the opportunities for self-expression that PBL affords combined with some aspects of traditional lecturing (e.g.,

teaching heat transfer calculations) would give students a positive insight into mechanical and design engineering.

1.1 Common First Year for Engineers

All students entering the honours Bachelor of Engineering programme at our institution complete a “Common First Year” core of modules that includes an Engineering Design Projects module that spans the year and involves three team-based design projects. The module participants meet for four hours weekly.

This Common First Year programme, initially delivered in the 2014-5 academic year, is intended to help students select a specific engineering discipline at our institution. The Common First Year is delivered by a group of engineers, mathematicians, and scientists. The overall curriculum for the Common First Year helps students:

- Achieve a foundation in physics, chemistry, mechanics, computing, and mathematics
- Gain experience identifying, formulating and solving engineering problems
- Begin to understand the engineering design process as a system
- Develop ability to analyse and interpret data
- Develop an appreciation of professional ethics and a sense of professional responsibility (socially and environmentally)
- Work effectively as individuals and teams
- Develop communication skills of use in engineering and across society

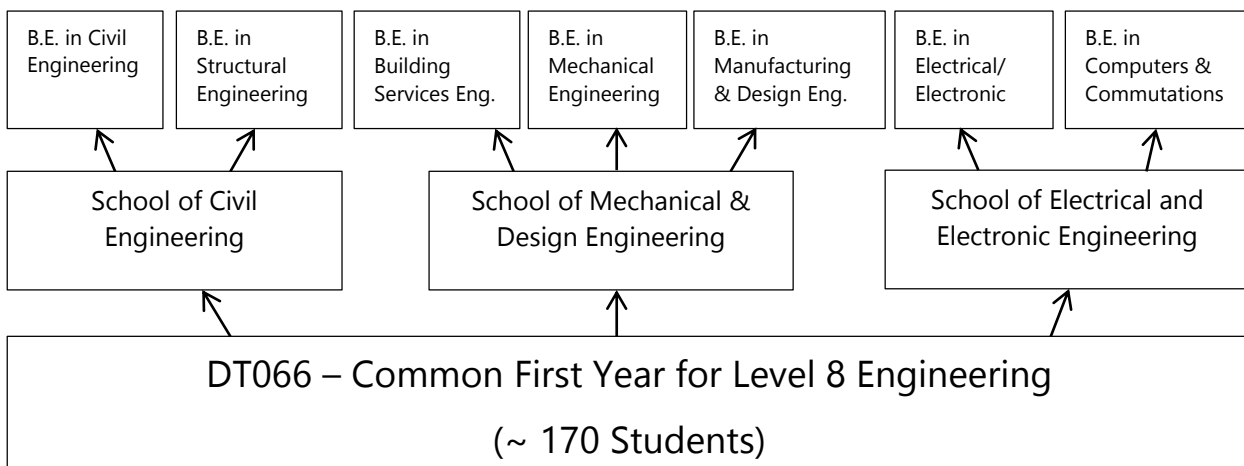


Figure 1: Structure of Level 8 engineering courses served by DT066 Common First Year course

Figure 1 shows an outline structure of the Level 8 engineering courses available and illustrates how these relate to the Common First Year core. At the end of first year students choose which course they want to pursue. The design project module gives students a taste of each engineering discipline. From each school’s point of view, this is a chance to persuade students to follow a career in their particular discipline.

1.2 Engineering Design Module

After completing the Design Projects module, students should have demonstrated the following learning outcomes, being able to:

- Operate effectively within design teams
- Apply engineering concepts and design tools to solve engineering problems
- Solve problems by following appropriate specifications and standards
- Communicate results, verbally as well as graphically
- Recognise the social role engineers play and understand relationships between technology and society

- Produce solutions to basic engineering problems using graphical methods
- Distinguish the roles various fields of engineering play in the overall profession of engineering

2 The Energy Cube

As illustrated in Figure 1, the School of Mechanical and Design Engineering provides one of the possible paths for students at our institution. It contains the specific fields of Mechanical Engineering; Manufacturing and Design Engineering; and Building Services Engineering. The Energy Cube project gives students a taste of each of these inter-related fields. Previously the Energy Cube project was offered by the Department of Building Services Engineering. To meet the goals of the Common First Year, that module was adapted to incorporate aspects of mechanical and manufacturing engineering.

As part of the new first year curriculum, the Energy Cube assignment asks students to design and build a model of a proposed headquarters building for a multinational corporation. Students are given a design brief that requires the building to be at least 55000 m³, modelled at a scale of 1/100. A minimum of 30% of the overall wall area must be glazing. The building should be designed to be as energy efficient as possible. It must make maximum use of available natural light and be aesthetically impressive. Students are advised that, for testing purposes, their models must be at least 200mm high and have a 100mm x 100mm hole in the floor to permit access to the testing equipment.

Each group is allocated a fixed amount of time and material to complete this design project. Each team is given: 2.85 m² of corrugated cardboard sheet comprised of 6 x 780 mm x 610 mm sheets, 20 clear plastic sheet (A4 sheets), and glue. The materials are analogous to the budget of the project; if a group requires additional material marks are reduced (5% for each additional sheet of cardboard used).

2.1 Week 1: Team Building and Introduction to Design

In Week 1, groups take part in a series of icebreakers to encourage teamwork. These exercises include a series of word games and a competition to build a paper aeroplane and see which can fly furthest. The groups are then provided with the project brief and given an introductory explanation of accepted design processes. Each team develops a design specification document and agrees on a set of evaluation criteria and measures. Lecturers emphasize the importance of the weekly team meeting and show basic project management tools. They provide templates that can be used for submitting the required design specification document, evaluation matrix, and weekly meeting minutes.

In Week 1, the objective is to set up a working relationship between the various team members. Teams have been chosen by the lecturers, with consideration given to distribution of gender, ethnicity and ability. We refined this approach during the course of the year in response to the phenomenological interviews conducted by the educational researcher on our team. In composing teams, we aimed to achieve diversity without leaving any single student isolated within the group. Because of the small number of females in the programme, we tried to place each girl on a team with another girl. We also tried to make the teams ethnically diverse, so that no one from a minority group was the sole ethnic minority on the team. We aimed for each team to have student from the top, middle, and bottom of the class with regard to past performance in engineering (as per Oliver-Hoyo & Beichner, 2004). We found that it was easier to accomplish once the students had been enrolled for a semester.

2.2 Week 1: Design Choice and Technical Analysis

In this session teams brainstorm ideas. They devise many different configurations and then use the design criteria developed in Week 1 to evaluate choices and determine which strategies are most likely to succeed. The lecturers give a short description of how to calculate the rate of heat that will be lost from an Energy Cube. To do this, teams are encouraged to calculate the U-values of all the different surfaces: floors, roofs, walls, and windows. Lecturers distribute a workbook that the students can use to calculate the steady-state temperature inside the cube in a methodical way. Using this heat-loss information alongside their evaluation matrix, each team begins whittling the possible design choices down to two.

2.3 Week 3: Final Design and Drafting

This stage of the project involves reviewing design choices within each team and determining the optimal approach. Teams then produce dimensioned construction drawings. They are also encouraged to compile a step-by-step construction plan to help maximize the four-hour construction period in the following week. Each team prepares final predictions for their cube's thermal performance. These predictions will be used as a point of comparison in Week 5, during performance testing. They are also used in each team's analysis of the test results and its final report and formal presentation.

2.4 Week 4: Build

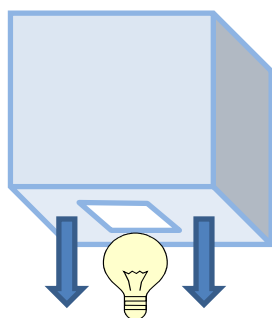
The build is compressed into a single four-hour session (with a bit of grace time granted at the start of Week 5 for final touches). Having a fairly strict time limit means that the process must be planned in advance in order to make best use of the time available. Teams are encouraged to plan tasks so they can be performed in parallel, and then these separate parts can be assembled at the end. Brevity also needs to be taken into account at the design stage when considering the complexity of a design. This means that some groups default to a simple box design. We have observed that it can be difficult to complete a two-layer cavity construction in the available time. Nevertheless, groups that plan carefully are able to accomplish complex designs within the four-hour block, as illustrated in Figure 2.



Figure 2: This team executing complex design for a geodesic dome within the four-hour period

2.5 Week 5: Testing

In Week 5, tests of thermal efficiency, lighting, and air-tightness are performed on the completed Energy Cubes. The thermal test consists of putting a 100-watt incandescent light bulb into the Energy Cube as a fixed output heat source. A thermocouple is inserted into the side of the energy cube about half way up. The cube is then left to reach a steady state while the students record the temperature every five minutes. The final temperature inside each cube, as well as the ambient temperature, is then recorded by the lecturer.



Team	DT	Refractor	Substrate	Source	0min	15min	20min	25min	30min	Exterior	Temp	Temp	Vol	T _{amb}	ΔT	ΔP
1	2	2	2	2	50.7	53.8	55.7	56.7	57.3	13.46	21.39	25.1	0.057	2.07	52.6	9.4
2	2	2	2	2	36.5	36.6	38.3	40.1	39.8	1.76	42.18	23.4	0.057	2.07	52.6	9.4
3	3	3	3	3	38.8	43.2	46.6	44.3	41.4	16.36	20.7	23.5	0.085	2.02	21.2	10.8
4	4	4	4	4	29.6	41.7	43.6	45.0	47.1	2.49	21.68	24.9	0.0515	2.35	24.7	12.9
5	5	5	5	5	40.3	42.5	43.8	44.7	45.1	2.52	23.48	25.1	0.057	2.07	20.8	6.2
6	6	6	6	6	31.7	39.1	39.2	39.5	39.7	4.0	16.35	14.04	0.07	2.07	15.4	1.9
7	7	7	7	7	33.6	35.8	34.1	34.6	34.5	14.53	26.41	25.4	0.081	2.32	11.3	10.6
8	8	8	8	8	22.4	28.5	50.3	51	51.2	5.7	13.04	3.4	0.032	2.47	27.0	15.5
9	9	9	9	9	33.6	37.1	44.6	48.6	49.7	5.0	18.21	18.21	0.056	2.02	26.8	5.2

Figure 3: Energy Cube thermal test with results recorded the old fashioned way

In the lighting test the Energy Cube is placed on top of a light meter and rotated through four points of the compass and the light level recorded. The average of these four measurements is taken. Then the Energy Cube

is removed and the exterior light level is measured. This aspect of the assignment can be honed in future years to take solar orientation into account during the design phase and reward good solar design during testing. This requires a more complex measurement system than we currently have in place, however.

For the final test, each cube is placed over a computer fan and a manometer is used to measure the pressure difference between the interior and exterior of the cube. This measure of air tightness is used as a metric for construction quality. The students record performance data on a whiteboard (as shown in Figure 3).

2.6 Week 6: Presentation

In the final week of the course each team makes a ten-minute oral presentation of its project for the lecturing staff and guests, who together represent the customer. Every team member is involved in the presentation. A designated team leader presents an introduction at the start and each member presents his or her contribution to the project. This is followed by conclusions and recommendations along with a reflective summary of the experience of working together as a team on this design project. To conclude the session, questions are presented to each team at the end of its uninterrupted presentation. Each team, as a group, provide a single written peer assessment of each of the other teams' content and delivery. The student evaluations are used in determining the overall presentation mark (as described below).

3 Assessment

"Assessment is integral to the overall quality of teaching and learning in higher education" (CSHE, 2014). With this in mind, the designers of this project assignment gave considerable effort to developing assessment methodology.

Marks are awarded to the each of the teams under the following headings: Design Specification & Evaluation Matrix (10%), Thermal Efficiency (20%), Thermal Prediction Accuracy (5%), Lighting (15%), Build Quality and Aesthetics (10%), Presentation (20%), and Report (20%). The presentation mark takes into account assessments by peers (20%) (see Figure 4) and lecturing staff (80%).

Peer Assessment Evaluation for Group: (Circle number of the group that is presenting)

1 2 3 4 5
 6 7 8 9 10

Student Names: _____

Please complete Figure 1 by 'ticking' the appropriate box. For example: a tick in the extreme left-hand box means that the statement on the left is true and is of 1+ (90%) quality. The boxes from left to right are abbreviated by:

EX = 90% - Outstanding VG = 75% - very good
 G = 65% - Good OK = 55% -adequate
 P = pass - 45%-Poor F = fail - 30% - very poor

Please add some general comments and feedback in the space at bottom of the page

	EX	VG	G	OK	P	F	
Content (65%)	////////////////////						Content
Objectives achieved							Objectives not achieved
Topic covered in depth							Superficial treatment of topic
Logically developed argument							Rambling; lacking continuity
Accurate presentation of factors							Much questionable/inaccurate issues
Good demonstration of key concepts							Lack of demonstration of key concepts
Presentation (35%)	////////////////////						Presentation
Attention-grabbing introduction							Uninspiring introduction
Convincingly argued							Argument lacks credibility
Clear and effective use of PowerPoint (inc. figures tables)							PowerPoint use unclear and ineffective
Reasonable length							Too long/short
Animated tone							Flat or stilted or nervous tone

Figure 4: Peer-Assessment Rubric for Team Presentation Session

For purposes of marking, thermal efficiency is evaluated from the temperature difference (ΔT) between the interior of the energy cube and the room. The highest ΔT (ΔT_{max}) gets 15% and other teams get $(\Delta T / \Delta T_{max}) * 15\%$.

Lighting is measured by dividing the interior Lux level by the exterior Lux level. The highest gets 15% and the rest get the same fraction as for the thermal test. Finally the percentage error in the predicted temperature is calculated and this fraction is subtracted from the maximum 5%. Construction quality is assessed from the pressure test results and aesthetics are judged subjectively by the lecturers.

With regard to individual contribution, Boud and Falchikov (2005) note that self-assessment helps equip students for life-long learning. The questionnaire completed by each student, in a place separate from their team members, required each student to evaluate the performance and contribution of each team member (including their own). Three categories were used for evaluation: Teamwork, Design Process, and Work Output. This exercise not only provided the opportunity for allocating individual marks, but also prompted students to reflect on the learning outcomes of the module. Gibbs (2009) concluded that giving one single overall mark to all members of a team often leads to 'freeloading' which means that the potential benefits of group work are lost and that students may feel their marks are 'unfair'. He encourages using secret peer assessment because it "produces a greater spread of marks and more distinction between individuals" (Gibbs, 2009, p. 9).

We generated each student's individual mark by applying a correction factor based on the results of the peer and self-assessment 'audit' conducted in Week 6 prior to the formal presentations. Our correction factor was weighted to reflect student attendance records.

Orsmond and Merry (2013) looked at high performing with non-high performing students and compared their treatment of feedback. They concluded that feedback should be designed to encourage development of students' self-assessment practices. Our team attempted to foster this type of development. Engaging the students in peer-to-peer learning by means of each team assessing other team's performance attempts to enhance their learning experience, and yield metacognitive gains (Toppings, 2005, p. 640). A rubric used within our College is shown in Figure 4. This instrument (by O'Dwyer, 2012) was influenced by the work of Freeman (1995). We supplied it to each team in Week 5, which prompted teams to pay attention to what was happening during the presentation session. It also provided guidance on what was expected, which supports the findings of Toppings (2005).

4 Analysis of Results of Feedback Survey

A short survey was distributed to students on the last day of the module to assess the level of satisfaction the students had with their group experience and also to assess the level of knowledge about engineering gained from completing the project.

Students expressed a high level of satisfaction ($\geq 70\%$) with their groups and their role within their groups. The results suggest that the team building exercises were worth dedicating a significant fraction ($1/6^{\text{th}}$) of the total time to. This is the same amount of time allotted to building the Energy Cube (which open ended survey responses suggested the students would prefer have more time to complete). However the relatively short amount of time available for the build means that teamwork is vital and tasks must be carefully planned (e.g., planning tasks to run in parallel).

The survey also sought feedback about what students felt they learned about engineering and what skills they developed during the module. The students valued two key transferrable skills highly—teamwork and problem solving—and they indicated they learnt these in the project. The students felt they had learnt the ability to perform heat loss calculations while possibly not regarding it as a core skill. Open ended responses suggested that some would have preferred a more 'mechanical' project such as something in the automotive or aerospace areas despite the fact that these constitute a small section of the engineering industry in Ireland. By contrast, manufacturing and building services engineering represent a much larger section of the industry here. The gender distribution is as encountered in all too many engineering courses.

	Strongly Agree	Agree	Neither	Disagree	Strongly Disagree	Sample Size
<i>The work was divided evenly between members of the team.</i>	16.5%	60.4%	11.5%	7.2%	4.3%	139
<i>I felt I was listened to in my group.</i>	36.2%	55.3%	5.0%	1.4%	2.1%	141
<i>Other members contributed equally to the team.</i>	22.7%	51.1%	12.1%	9.9%	4.3%	141
<i>I felt I played a valuable role within our group.</i>	28.6%	57.9%	12.9%	0.0%	0.7%	140
<i>I feel more confident working in teams than before.</i>	27.1%	32.9%	33.6%	5.0%	1.4%	140
<i>I have a better idea of what engineers do.</i>	12.9%	52.1%	26.4%	7.1%	1.4%	140
<i>I feel more confident that engineering is for me.</i>	25.7%	42.1%	28.6%	2.9%	0.7%	140

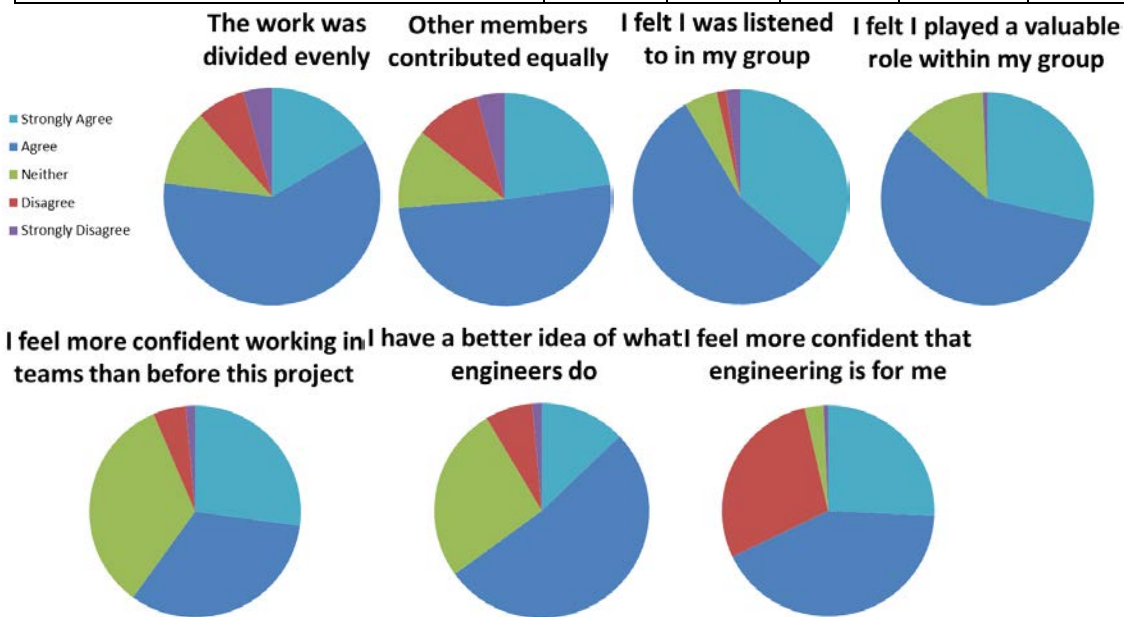


Figure 5: Student feedback on teamwork and knowledge of engineering gained during the course

	Drawing & Graphics	Heat Loss Calculation	Team Work	Problem Solving	The Design Process	Communicating Results	Valid Sample Size
<i>Which of the following topics we covered do you feel will be most useful to you as an engineer?</i>	11.5%	10.0%	31.5%	29.2%	15.4%	2.3%	130
<i>Which of the following skills do you feel you learnt?</i>	9.2%	22.9%	26.7%	21.4%	16.8%	3.1%	131

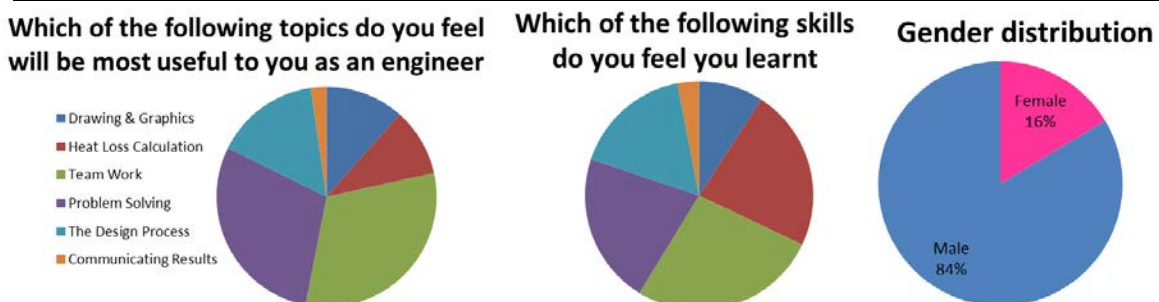


Figure 6: Student feedback on learning outcomes and class gender distribution

5 Conclusions

A design-and-test project has been described in this paper. It requires students to build a model of an energy efficient, aesthetically pleasing structure that makes maximum use of available light. It provides students with experience in mechanical, manufacturing and building services engineering. The content of the module has been described in chronological order.

A breakdown of the assessment of student performance has been described including a description of the peer assessment used. Finally, an analysis of the student survey data has been presented. Overall, the students appear satisfied with the teamwork section of the module. They felt it improved their knowledge of engineering while leaving and covered a range of the designated learning outcomes for the course.

The module provides a way for students to learn about the critical importance of energy efficiency, in particular in buildings, and how we have a responsibility to make buildings and processes as energy efficient as possible. They learn about the ways that energy is wasted and develop ability to quantify these aspects of design. They learn how good design leads to a good final product and that planning is essential. Finally they learn how energy efficiency can be designed into a building, machine, or process.

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