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## **The Biosystems Engineering Design Challenge at University College Dublin**

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**Abstract.** *The Biosystems Engineering Design Challenge has recently become an academic module open to all undergraduate students at University College Dublin. The focus of the module is on designing and building a working, bench-scale device that solves a practical problem relevant to*

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*Biosystems Engineering. The module provides an opportunity for students to learn about engineering design, project management and teamwork. Enrolled students are split into teams of up to seven and meet an assigned mentor each week during a semester (12 weeks) to solve a specified problem. The objectives thus far have focused on water-driven electricity generation, treatment of greywater from domestic buildings, and biofiltration of malodors from food waste. The assessment criteria include teamwork, minimisation of expenditure, device design, innovation, operational safety, system performance, report writing and appropriate use of biological and recycled materials. External experts evaluate each entry and substantial cash prizes are awarded to the top teams. Students receive individual academic grades based on their contribution. Feedback on the module has been very positive from both inside and outside the University. The most recent developments have been the introduction of an online project journal for each student and the involvement of biosystems engineering graduate students as mentors.*

**Keywords.** Biosystems Engineering, academic module, engineering design, project management, teamwork

## Introduction

The Agricultural and Food Engineering degree at University College Dublin (UCD) was rebranded as Biosystems Engineering in 2004; this followed a review which suggested such action would:

- be compatible with trends in North America towards “Bio” engineering titles;
- address falling student numbers and make the discipline more attractive to school leavers;
- reflect the wide scope of research and academic activity within the discipline and particularly its relationship with biology and life sciences.

Students may enter the Biosystems Engineering degree in first year at UCD directly from secondary school or alternatively they may choose the Biosystems option after spending first year in an Undenominated Engineering program. Other degree options include Bioprocess, Chemical, Civil, Electronic/Electrical, and Mechanical Engineering.

It was acknowledged that the new title for the undergraduate program offered the opportunity to integrate engineering and biology in a more explicit manner. One approach that was used was to initially launch a competition called the Biosystems Engineering Design Challenge for first year (stage one) engineering students, which was eventually implemented as a Stage 1 module on the Biosystems Engineering curriculum and available to any student in the University.

## Initial design competition

The Biosystems Engineering Design Challenge was introduced in 2004 as a competition open only to first year UCD students in Biosystems Engineering and Undenominated Engineering. The competition was co-ordinated by a committee which included four staff members from the subject area along with the Engineering student advisor. Funding was sought from industry to provide both substantial cash prizes for winning teams and budgets to cover expenditure on materials. A three year 7500 euro sponsorship agreement was provided by Greenstar, Ireland's largest integrated waste management company.

The focus of the competition was on designing and building a working bench-scale device that solved a practical engineering problem relevant to Biosystems Engineering. It provided an early opportunity for students to learn about engineering design, project management and teamwork in an environment that was both rewarding and enjoyable.

The aim of the 2004/05 challenge was for teams of three to five students to design, build and operate a biologically-based bench-scale treatment system to recycle grey water within apartment-sized domestic buildings. In other words, teams had to design and build a device to treat waste wash water from kitchen sinks, dishwashers, washing machines, showers, and baths so that the water could be reused as supply water for toilets. The potential for water conservation utilizing such a system is very significant as about one third of the 270 litres of water used daily in the average Irish domestic household is flushed down the toilet. The theme of the competition reflected the emphasis of the Biosystems Engineering program on integrating engineering and biology for sustainable development and service to biology-based industries.

Participation in the competition was compulsory for the eight first year Biosystems Engineering students and voluntary for Undenominated Engineering students, five of whom took part. The students were only in the second week of their first academic year in the University, so the process of team formation required much prompting. Four teams were formed and had a further eight weeks to design and build a working bench-scale model. Teams initially participated in

group workshops on engineering design, time management, and teamwork. The students were requested to select a team name and appoint a leader.

A mentor was assigned (from Faculty) to each participating team. The role of the mentor was to facilitate teamwork and the achievement of the end goals while not actively participating in the design process itself. Teams met with their mentor every week and also kept in contact by email and telephone on a regular basis. Guidance was provided on the challenge rules, team building, assessment criteria and a suggested schedule of activities throughout the competition period. There was a one hour scheduled meeting slot once per week; however teams were encouraged to meet at other alternative suitable times also. The UCD Blackboard e-learning web site was used for further discussion, guidelines and updates.

.An important aspect of the project was encouraging students to think creatively, and economically, about the materials used in the project. Thus, each team was allocated a small budget of 150 euro for materials. Participating teams were reimbursed upon production of receipts for goods at the end of the competition. The final assessment criteria included teamwork, minimization of expenditure, device design, innovation, operational safety, system performance, report writing and appropriate use of biological and recycled materials.

The teams assembled their devices in the laboratory for performance testing one week prior to final judging. A synthetic mixture of grey water was made up from detergents, food products and water. Five litres of the mixture was poured into the inlet reservoir of each device and each apparatus had to produce one litre of treated water within five days of startup. The Chemical Oxygen Demand (COD) was measured in inlet and outlet water samples taken from each system in order to provide an indication of performance.

Each device was based on the principle of utilizing the nutrients in the grey water to grow plants. However, there were significant differences in the overall designs. Systems incorporated a range of processes including grease traps, sand filters, geotextile membranes, evapotranspiration and air pumps. The COD reduction in the systems varied from 38% to 98%. Further reduction in pollutants may have been possible following more extensive testing. The expenditure on materials ranged from €38 to €75 per team.

External experts (two engineers and a scientist) were invited to the University to determine the best team performance. The adjudicators examined the final reports and posters, and discussed the designs with the teams and mentors on the basis of the assessment criteria. The judges commented favorably upon the standard of designs, teamwork and enthusiasm of the participants in the competition. Substantial cash prizes were awarded with the winning team (Team "Bigger is Better") receiving 1000 euro.

## **Academic module**

Due to its initial success and positive feedback from students, the challenge was introduced as a formal five-credit module in the UCD curriculum in the 2005/06 academic year. Due to the introduction of semesterisation, it was possible for students from outside of the Biosystems Engineering and related programs to participate. A total of 23 students participated including five from Agricultural Science. Four teams were formed, although the process of team formation was rather elongated because a slot was not allocated to the module on the university timetable, and some students withdrew from the module within the first couple of weeks of the semester. Therefore, it took some time for teams to find a suitable meeting time and venue.

The inspiration for the theme of the challenge came forward after an article about the initial competition was featured in the national daily newspaper "The Irish Times" by its science editor (Ahlstrom, 2005). It highlighted how engineering students were concerned about challenges to

the environment. Subsequently, one of the newspaper's readers (Ms. Audrey Boudren) wrote a letter to the co-ordinator of the Biosystems Engineering Design Challenge, suggesting that the next competition should address the well-publicised odour nuisance caused by Dublin city's sewage treatment plant at Ringsend.

The selected challenge was to design, build and operate a biological bench-scale device to filter malodorous air from food waste. It was decided it would be safer and more convenient to test each team device using a rotten egg rather than sewage as the odour source. A format similar to the previous year was used. Students had 11 weeks in the semester to build their systems plus an additional three week vacation period. Team budgets were reduced to 100 euro as it was considered sufficient based on experience.

All four teams successfully designed and built devices which included parts from water heaters, milking machines, air pumps, variable speed fans, compressors, charcoal filters, water hoses and various biofilter media. Performance tests were carried out on the devices in the penultimate week of the semester. At the time of testing, the hydrogen sulphide emissions from the rotten eggs were not sufficient for the intended purpose, so pig slurry was added to the mix. The biofilter systems achieved excellent performance with very high reduction of hydrogen sulphide (Table 1).

Table 1. Biofilter performance results

Team Name	Empty Bed Residence Time (s)	H <sub>2</sub> S Removal Efficiency (%)
BNM	1.5	99.2
Sweet Smell of Success	2.5	99.0
The Ag Boys	2.0	95.0
The Incredibles	5.7	99.3

On the final assessment day, Ms. Boudren who inspired the theme of the Challenge was invited for lunch in the University along with the external adjudicators, one of whom actually worked at the aforementioned Dublin city sewage treatment plant. This was considered to be a token of gratitude along with affording the opportunity of a useful discussion on the technical aspects of the odour abatement solution which could be seen in the student designs. Despite having a slightly poorer device performance compared to other groups, the winning team was the "Ag Boys" (all Agricultural Science students) who displayed excellent teamwork and did better in addressing the many criteria involved in the module. The module co-ordinating committee met afterwards to determine the individual student academic grades which were adjusted from the team average based on the mentor's evaluation of their contribution.

The 23 students who participated in the Challenge were invited to submit a paper for the UNACOMA Vision Award, an event organized by the European Society of Agricultural Engineers (EurAgEng) to provide an opportunity for younger people to demonstrate their vision of agricultural and biological systems engineering in the future. Eight of the students came forward to co-author a paper "Integrating Engineering and Biology – The Final Frontier". The students demonstrated a significant commitment to the task by meeting several times during the summer vacation to discuss their collected literature. The submitted paper (Delahunty et al., 2006) dealt with how the Biosystems Engineering Design Challenges to date on treatment of greywater and polluted air could be used in the design of closed loop environmental control systems in a space station (Fig. 1). The proposed model contained four components in the life support system: **C**ontrolled Environment, **R**egenerating and Resting, **E**ating and Drinking, and finally **W**orking and Energy Production, (**C.R.E.W**). It was suggested that each module should specifically cater for one need but also provide overlap for other regions to maximise recycling potential between modules.

The paper was presented by one of the UCD students to an audience of over 200 delegates at the World CIGR Conference closing ceremony in Bonn, Germany in September 2006 and finished a highly commended runner-up in the UNACOMA Vision Award. All eight students travelled to Bonn courtesy of UCD and thoroughly enjoyed the experience.

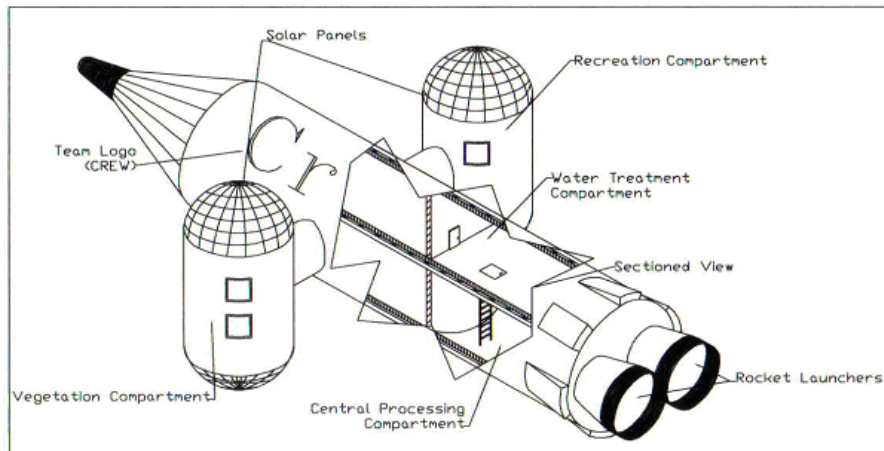


Figure 1. An overall view of the concept space station with modules for specific tasks and human needs (Delahunty et al., 2006).

## Current Challenge

Now in its third year, it was planned to limit the intake to the Challenge to 30 students due to resource issues but because of great demand, the final enrolled number was 42 (6 teams) representing 13 different program streams from Engineering, Science and Agricultural Science. The involvement of Biosystems Engineering graduate students as mentors also facilitated the extra numbers. Due to more suitable scheduling, it was possible to distribute students from various backgrounds more evenly across the teams than heretofore had been achieved. This multi-disciplinary approach for the module had been recommended during an accreditation of the Biosystems Engineering degree course in the previous year by Engineers Ireland (equivalent to ABET accreditation). The introduction of the Challenge had been noted by the accreditation panel as a very positive move towards problem solving in teams, thus assisting in meeting the organisation's assessment criteria for the degree.

This year's theme was sustainable energy as it had been established as a significant part of the Biosystems Engineering research strategy. It was also very timely because a prestigious 3 million euro Parsons Energy Research Award had been secured from the Irish Government's Department of Marine, Communications and Natural Resources. The idea of a biofuel challenge was discussed by the co-ordinating committee but it was felt it might have resulted in some hazardous and uncontrolled efforts by the students. Therefore, the objective was finally set to design, build and operate a water-driven electricity generator to produce no more than 12 volts for up to five minutes. A maximum of 20 litres of water could be used. The height of the model had to be less than 1.2 metres.

Further modification of the assessment criteria was necessary. It was felt that the issue of teamwork had not been highlighted sufficiently to students in the previous two years, so this was explicitly stated in the most recent guidance document and mentioned several times during the initial group meeting. Further discussion among the co-ordinating committee on how students

could be graded individually led to the introduction of an online project journal for each student. A one-page report (based on a provided template) had to be submitted via Blackboard each week as a record of every meeting and the tasks to be carried out by both the individuals and each team as a whole. The graduate student mentors were also asked to complete assessment forms to indicate their evaluation of the contribution of each student to team performance.

While the module fits in with the University's policy to introduce alternative teaching and learning strategies compared to the conventional lecture, many obstacles have arisen. It has proven difficult to find a suitable venue for weekly meetings. The traditional lecture theatre layout does not lend itself to facilitate meetings, so teams are encouraged to meet at the allocated room but to be flexible enough to move to a nearby vacant room or even continue their discussion over a cup of coffee. There is also a requirement for laboratory and/or workshop space to have appropriate supervision staff present at all times. This has also proven difficult, therefore the Challenge tends to be devised in order to reuse easily accessible household equipment with minimum alteration.

Further efforts have been made in being more concise in allocating marks to the various assessment criteria (Table 2) to allow the process become more transparent and clear to the students, mentors and external adjudicators. The aim is to award academic grades based on feedback from the external adjudicators and discussion between the mentors and the co-ordinating committee.

Table 2. Assessment criteria

Criterion Number	Description	Comment	Marks available
1	Teamwork	Based on assessment by judges & mentors.	15
2	Device performance	Voltage & current (average power) over 5 minutes	15
3	Final Report (approximately 10, A4 pages)	Including minutes of team meetings, outline of concept to implementation phases, photos of building and testing, design calculations; costs	15
4	Project journal	Completeness	10
5	Electronic version of accompanying poster to describe the design	Clarity and succinctness; ability to communicate	10
6	Overall device design	Final finish on device, ease of operation, durability, easy to carry & assemble, practicality for scale up	10
7	Safety	Safe to use	5
8	Innovation	Novel concepts	5
10	Biological materials	Use of biomaterials	5
11	Environmentally friendly	Use of recycled materials, low energy input	5
13	Expenditure	Cost of materials within budget	5
TOTAL			100

All of this year's student teams successfully built and operated working devices which met the objective of water-driven electricity generation. A variety of recycled parts were used in the designs such as a car wiper blade motor, a stereo cassette player motor and pieces from discarded childrens' toys. The Challenge was won by "The Sensational 7"; not only did they display great teamwork but they also had the best technical performance from their device. However, there was some disquiet among other participants as the winning team was the only one with a student from outside of first year/stage, in this case stage 3. While the original competition was designed for first year students, the recent semesterisation made it possible for students from a more advanced stage to enrol in the module.

It is considered that having graduate students as mentors works better with them being able to relate well with undergraduates and also relieving pressure on Faculty time. The mentors were asked to grade student contributions to teams using a questionnaire (Oakley et al., 2004). Most students readily submitted their online project journal page and it is hoped that this will encourage them to be more disciplined in submitting work for other subjects. Positive feedback has been received on the mentoring scheme, the teamwork aspect, and the opportunity to adopt a "hands-on" approach to problem solving. Students said that they liked not having to take a written exam at the end of the semester and that they would highlight their participation in the Challenge on their resume.

Overall, the students who participate in the Biosystems Engineering Design Challenge appear to have a positive attitude towards the discipline although the number of students who enter the degree program has not increased significantly since the inception of the module. However, it does create an awareness of the program among students who traditionally would not know of its existence. There seems to have been a positive impact on students in Agricultural Science, some of whom have joined the sister program in Engineering Technology (a program recognized by ASABE).

Further developments in the module could include more formal training of graduate students in their role as mentors and the possibility of their gaining course work credit for this activity. A teamwork exercise could be introduced at an early stage to help team members to get to know each other before they embark on solving the main problem. More appropriate meeting and workshop space would be beneficial in the future. Finally, the assessment criteria must be reviewed on a regular basis to ensure that they reflect the learning outcomes that must be achieved. The experience to date would suggest that assessment appears to be one of the most controversial concerns in problem-based learning (Savin-Baden, 2004).

## **Conclusions**

The Biosystems Engineering Design Challenge has recently become an academic module open to all first year students at University College Dublin. The focus of the module is on designing and building a working bench-scale device that solves a practical problem relevant to the Biosystems Engineering discipline.

The assessment criteria include teamwork, minimization of expenditure, device design, innovation, operational safety, system performance, report writing and appropriate use of biological and recycled materials.

The most recent developments have been the introduction of an online project journal for each student and the involvement of graduate students as mentors. The module has promoted a positive learning experience for students and created an awareness of the Biosystems Engineering discipline.

Further development of the module could include the introduction of more appropriate meeting and workshop space, the incorporation of teamwork exercises and further training of mentors. Assessment criteria must be reviewed on an ongoing basis.

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