CASE STUDY OF A PROBLEM-BASED BRIDGE ENGINEERING DESIGN COURSE

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ABSTRACT

This paper presents the problem-based Bridge Engineering project taken as part of the multi-disciplinary Engineering Design course during the second year of the Bachelor of Engineering Degree programme at Trinity College Dublin. The Engineering Design course runs throughout the academic year and consists of three modules (projects), namely the design and construction of a model railcar (mechanical); a bridge to support the rail track (civil), and a signalling system to control the railcar movement over the track (electronic). Working groups of mixed ability are given written project specifications, timelines and submission deadlines. The projects, which have a plurality of solutions, serve as an engine for invention to assist the students in achieving a range of professional, transferable and social competences under the guidance of a team of professors and demonstrators. Skills must be independently learned and developed by the students in formulating, analysing, optimising and evaluating the performance of their designs and communicating their ideas effectively. The competences are continuously assessed by the teachers through full project portfolios (oral presentations, working models and written project reports). The motivation among the students is high with considerable enthusiasm and interaction among the students.

INTRODUCTION

This paper presents the problem-oriented, project-based Engineering Design course, focusing in particular on the Bridge Engineering project, taken during the second year of the four-year Bachelor of Engineering (B.A.I.) Degree programme at the School of Engineering, Trinity College Dublin. The School of Engineering comprises the Departments of Civil, Structural and Environmental Engineering, Mechanical and Manufacturing Engineering, and Electronic and Electrical Engineering.

At present, about 170 students are accepted onto the B.A.I. programme annually. All of the students are given a good foundation in the fundamental concepts, principles and methodologies of the different engineering disciplines during the first two years of the programme after which they specialise in their chosen discipline in the third and final years. The first year serves to consolidate the study of mathematical and physical sciences. In the second year, the subjects that are common across the engineering disciplines are studied to progress associated mathematical knowledge and skills; to develop the ability to formulate, analyse and synthesise solutions to a broad range of basic engineering problems and to introduce the skills of carrying out engineering design projects. A combination of traditional lecture-driven and project-orientated, problem-based approaches is used along with coursework, tutorial assignments and laboratory practical sessions to achieve these aims. The Mathematics, Computer Science and Engineering Science subjects and a range of subjects closely aligned to the engineering departments (Solids and Structures, Thermo-fluids and Electronics) are mainly taught using a lecture-driven approach.

These courses are largely assessed by annual examinations along with some continuous assessment components.

A project-orientated, problem-based approach is used for the Engineering Design course which has been structured to oblige the students to grapple with the reality of designing and building models, thereby gaining experience in practical problem-solving in multi-disciplinary settings. Many of the skills must be independently learned and developed by the students in working through the different tasks necessary to complete the projects. The students must work effectively in teams to analyse, optimise and evaluate the performance of their design solutions with respect to specifications and communicate their ideas effectively in the form of oral presentations and written project reports. This is the first occasion in the B.A.I. Degree programme that the students are exposed to such problems and all the associated skills and organisation required. This paper presents the Engineering Design course, focusing in particular on the civil engineering module (Bridge project), including its organisation, specific aims and the development and assessment of professional, transferable and social competences.

OVERVIEW OF ENGINEERING DESIGN COURSE

The Engineering Design course runs throughout the academic year and consists of three modules, namely the design and construction of a model railcar (mechanical); a bridge to support the rail track across a chasm (civil), and a signalling system to control the movement of the railcar along the track (electronic). The class of about 170 students is divided into 40 working groups comprising four or five students of mixed ability. The mechanical engineering module runs over weeks two to nine of the academic year. The groups are required to design and construct a light-weight model railcar to safely carry a payload as quickly as possible along a standard racecourse. The civil engineering module runs over weeks 10 to 16 of the academic year and the groups are required to design and construct a model bridge to support the track across a chasm included in a racecourse track. The electronic engineering module runs over weeks 17 to 24 of the academic year and the groups are required to design and implement a signalling system (including hardware construction and software design) to control the movement of the railcar over the track.

The students are given a series of written specifications for the project outcomes. The students work in the same groups throughout the duration of the course and he or she uses the group as a necessary forum for professional development and learning. The students are given a lot of responsibility as they focus on what needs to be learned to complete the projects. The scale of the projects is such that it requires teamwork as a co-ordinated effort with all of the students participating fully in all aspects of the projects which have a plurality of solutions. The competences are continuously assessed with set deadlines for submitting the project portfolios, comprising oral presentations, working models and common project reports. Ample guidance is provided by three professors and a team of trained demonstrators from the three engineering departments. Each working group is given one formal contact hour per week for the mechanical and civil engineering modules and two contact hours (laboratory practical) per week for the electronic engineering module.

The working groups that have developed the ten fastest railcars and the ten best bridges (ranked according to the performance ratings) compete in a competitive race held at the end of the academic year. The railcars are timed along a 6.4m long racecourse that includes the bridges, a curve in the track of radius 0.8-m and 5% upward and downward gradients. A prize fund is awarded to the teams that complete the racecourse in the fastest time. The remainder of this paper focuses on the Bridge Engineering project.

BRIDGE ENGINEERING PROJECT

The students are required to design and construct a model bridge that will support the track across a chasm included along racecourse track in the final competition. The bridge must meet the following specifications:

- Clear span of 1.6m and free standing with the ends of the bridge relying only on point contact support (no horizontal reaction).
- Bridge deck must be continuous and at least 80mm in width (to accommodate the rail track which must not be relied on for strength) and must rise at a slope of 1:20.
- The tops of the deck and the bridge supports at either end must be flush to allow a smooth transition for the track.
- Bridge must allow the passage of the railcar and its payload which together could be up to 100 and 150mm in width and in height, respectively.
- Any construction materials can be used but the total bridge mass must be less than 420g.
- Capable of carrying a worst-case scenario load of 1.5kg placed at its mid-span without appreciable deformation.

The working groups are given a timeline over which the bridge project is to run and deadlines for the coursework submission. A project manager, who is the principal point of contact between the lecturer and the group, is appointed by the students in each group. Some careful planning is needed for the project to run smoothly. The project manager is also responsible for submitting the coursework punctually. The students are provided with tutorial reading material but they are also required to seek additional information from recommended sources themselves.

After the students have been given some instruction on the merits and limitations of the different design options, the groups work in their own time during the first week of the project to prepare a bridge design concept. The bridge should be in essence a truss design so that all of the groups have a good chance of producing a working model but the students are encouraged to think of alternative and potentially better ways of meeting the specification so the more inventive can go beyond the safety net provided to produce a more innovative design. Whilst most of the groups use balsa wood as the main construction material, some use plastic sheet or tubing, cardboard, expanded polystyrene or aluminium sheet. The structural members are generally secured together using pin connections or adhesive glues. The capacity of the Civil Engineering workshop is very limited so that the groups must source the materials and build the models themselves using their own hand tools.

The project manager of each group presents the design concept (including novel features, preliminary force analysis, materials) using engineering drawing in a class session to peers and colleagues for critical discussion and feedback during the second week. At this stage, the group cannot change the basic design concept but may make some minor changes based on the feedback received.

During weeks three to five, the groups carry out a numerical analysis under the guidance of a professor to assess the load–deflection behaviour of the proposed bridge. In the third week, the students are briefly introduced to STAAD Pro-QSE [1] frame analysis program during a one-hour tutorial session after which the students work through a real problem (namely the analysis of a structural steel roof truss for a supermarket) to become familiar with the software package. The groups are required to develop a plain-strain model of the proposed bridge (simply supported structure with either pinned and/or fixed connections of the members depending on the construction) which is analysed for deflections during the fourth and fifth weeks. The students must research the pertinent engineering properties of the materials for input to the numerical analysis. The groups optimise their designs by changing the geometrical arrangement, material and/or sectional properties of the members to limit the predicted deflection under the worst-case scenario load condition of 1.5kg at its mid-span.

During the sixth week, the groups build the physical models which are tested during a laboratory session before their peers and colleagues during week seven. The mass (m) of the models are measured and the bridges are checked against the specifications. The actual deflection (δ) of the bridge under a static 1.5kg load that is placed above the deck at its mid-span is measured using a dial gauge (Figure 1).

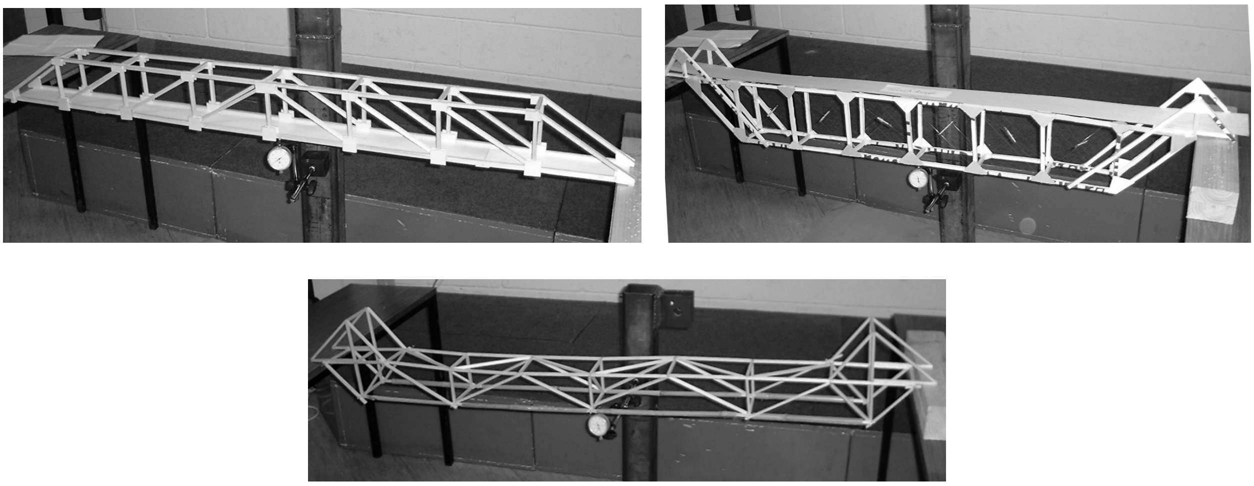

Figure 1: Load–deflection testing of model bridges.

The students are made personally aware of ways in which the designs could be improved and the practical problems that can arise from poor design and construction (Figure 2). The bridges are assigned a performance rating (R_2) based on having the lightest model and the least deflection (Equation 1). The lower the R_2 value the better the performance of the model using these criteria.

$$R_2 = m^2 \delta \tag{1}$$

A full design portfolio is prepared by the group and submitted at the end of seventh and final week of the project. Each student in the group is required to clearly state his or her degree of involvement in the coursework elements. A project report including an explanation of the reasons for choosing the design concept and its novel features; the engineering properties of the construction materials; the approach used in modelling the bridge; the input parameters and results of the numerical analysis; the manufacture of the physical model and its predicted and actual mid-span deflections.

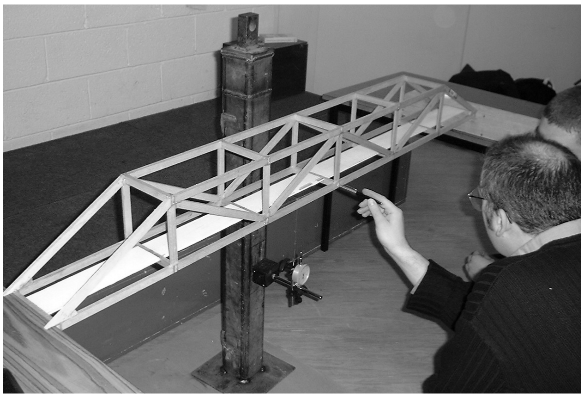

Figure 2: Critical feedback on bridge design.

ASSESSMENT

The Engineering Design course is continuously examined by coursework alone. There is no formal end-of-year examination. The students are advised that the overall mark awarded to the working group on completing the course is calculated as follows:

$$\text{Group mark (\%)} = \frac{1}{3}\left[(A.B.C)^{1/3} + \frac{2}{3}(A+B+C)\right] \tag{2}$$

where A, B and C are the percentage marks awarded for the mechanical, civil and electronic engineering modules. Table 1 sets out the marking scheme for the civil engineering module (Bridge project). Credit is also given to the more inventive groups that go beyond the safety net provided to produce more innovative designs.

Bridge Engineering Module	**B mark (%)**
Presentation of concept design	15
Numerical analysis	20
Quality of physical model	15
Performance rating of bridge	10
Design portfolio and level of difficulty of design	40
	100

Table 1: Assessment of Bridge Engineering project portfolio.

The marks awarded to the working groups are posted on the Departmental notice boards or the course website on the College intranet shortly after the completion of each module. The students are also advised that their individual marks for the course are based on their group mark, attendance record and contribution to the working group. A satisfactory mark must be obtained by the student in each of the three modules as well as an overall course mark of at least 40% to successfully pass the course.

SUMMARY

A multi-disciplinary, problem-based Engineering Design course taken by about 170 students during the second year of a Bachelor of Engineering Degree programme at Trinity College Dublin has been presented. Working groups of typically four or five students of mixed ability are given a series of written specifications, a timeline and submission deadlines for the civil, mechanical and electronic engineering modules. The course has placed the students in the centre of the learning process with the learning responsibility having largely moved to the students from the teachers who now acting primarily as facilitators.

Skills must be independently learned and developed by the students in working through the different tasks necessary to complete the projects which have a plurality of solutions. The projects serve as an engine for invention to assist the students in achieving a range of professional, transferable and social competences. The students must work effectively in groups to formulate, analyse, optimise and evaluate the performance of their design solutions under the guidance of a team of professors and demonstrators. There is a high degree of focus on the development of communication skills, learning competence and the ability to work in multi-disciplinary settings, project management and team-building skills, information technology skills, as well as the further development of the confidence and self-esteem of the students.

The competences are continuously assessed by the teachers through full project portfolios (oral presentations, working models and common reports) to validate the process. The motivation among the students is high, as evident from the amounts of time that they spend working on the projects, and considerable enthusiasm and interaction is generated among the students with about 95% student participation achieved.

ACKNOWLEDGMENTS

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REFERENCES

1. STAAD Pro-QSE, Research Engineers International, www.reel.co.uk