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Innovations in Undergraduate Engineering Mechanics Education: Use of Team-Based Research-Led Project Methods for Large Student Cohorts*

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As a cornerstone subject for all undergraduate engineering degree programmes, mechanics is best taught from fundamental principles and by reinforcing students' learning through active learning strategies. This approach provides students with a solid understanding of basic concepts before they subsequently study more advanced topics such as dynamics, control, solid mechanics and fluid mechanics. MEEN10030, Mechanics for Engineers, is a compulsory module taught annually in Semester I to 260 First Year students at University College Dublin, Ireland's largest university. The syllabus topics include forces, Newton's laws of motion, statics in two and three dimensions, equilibrium, friction, trusses and cables, distributed forces, centres of mass and centroids, motion, and kinematics of a particle and of a rigid body.

Traditional teaching of this subject relies solely on formal lectures and tutorials, without any laboratory sessions or student assignments, both of which are resource intensive. Five years ago, following a programme review in 2006, this module was completely revised and the subject material was rationalised with regard to what is taught in subsequent Second Year modules. Three entirely integrated laboratory sessions were developed so that groups of students would complete a variety of analytical and enquiry-led exercises in numerical, graphical and written form. A more recent additional major initiative, introduced three years ago in 2008, provides team-based assignments to the entire 260 students in which groups of up to five students are set a design challenge directly related to one specific topic from the course material. These changes have proven popular with students and have led to improved learning outcomes and student performance without compromising on academic standards. This paper describes these innovative developments in which Irish engineering students have opportunities for research-led active learning in this manner.

Keywords: research-led; team-based; undergraduate teaching; design project

1. Introduction

The understanding and application of Newton's three laws of motion is fundamentally important in all university level engineering programmes. A solid foundation in these concepts is needed to understand more complex engineering subjects such as mechanics of materials, fluid mechanics, dynamic systems, machine design and control theory. In a university environment, it is common practice to teach Newtonian mechanics through theoretical analyses, ignoring the tangible everyday connections that students may actually have with the subject. By introducing practical sessions where fundamental mechanics principles are demonstrated and experienced personally by each student, a stronger mental connection can be made with the theory and students can actually see the studied principles being applied in action. Relating theory to aspects of actual research projects from our group [1–4] and elsewhere [5–7], and from best practice demonstrators [8–10] can further enhance the link between theory and practice. With careful planning, this can be positively reinforced through frequent multi-level interactions between postgraduate students and undergraduate students.

The active involvement of students in laboratory sessions significantly stimulates understanding in the context of engineering education. Over the course of the past decade, however, scarce infrastructural resources (space, technicians, equipment and hardware) have compounded the effects of financial constraints to force engineering schools in Ireland and in other countries to rely increasingly on demonstrations to large groups of students or on computer simulations [11]. In many mechanical engineering degree programmes, the capital equipment required for laboratory sessions is prohibitively expensive and laboratory group sizes for students tend to be too large to provide genuine 'hands-on' experience. When teaching engineering mechanics at University College Dublin, however, we deliberately ensure that students in most laboratory sessions work in small group sizes (3–5 per group) and in teams where each student is personally required to use single items of laboratory apparatus. Where multiple sets of apparatus are not

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available, different students are expected to take lead responsibility for different aspects of team assignments and then to transfer their learning to each other. In such laboratory based learning sessions, students are required to use a broad range of tools (experimentation, simulation, validation, statistical analysis, etc.) to fully explore the subject matter upon which corresponding lectures are based.

This approach to teaching blends the best methods for concept-based learning [12–14] and problem-based learning [7, 8, 15]. This firstly promotes a student's understanding of concepts in engineering science and then develops their ability to visualise real-world problems in terms of underlying fundamentals, and subsequently empowers them to quantitatively analyse and obtain solutions to physical problems. This is consistent with Kolb's model of learning [16], which begins with concrete experience, proceeds with reflective observation, abstract hypothesising and conceptualisation, and ends, before restarting, with active experimentation. The Kolb model for learning engineering promotes a balance between all modes of learning, in which there is equal focus given to experiential activities as well as to theoretical knowledge. In the 21st Century, it remains an imperative that engineering students are provided with a foundation on which to build and a place in which they can explore the physical manifestation of theoretical concepts [17].

There are many excellent text books in undergraduate mechanics [e.g., 18–20], all of which we recommend equally to our students, who are expected to use any one of these books. The philosophy adopted by all of these authors is to develop a fundamental conceptual understanding of the physical mechanisms associated with mechanics and subsequently to extend this into an ability to analyse and solve physical problems. This early emphasis on the issue of cognitive understanding is, in our view, critical to a proper appreciation of mechanics at an undergraduate level. Each of these authors place strong emphasis on this point although it is interesting that, while engineering educationists refer to this as concept-based learning, none of these authors ever refer to this approach explicitly as concept-based learning. It is important to realise that this initial emphasis on understanding is complemented by the teaching style we adopt, whereby we aim to develop each student's ability to visualise, formulate and solve physical problems using quantitative mathematical techniques.

The present paper describes some of the project-based approaches that we have developed and introduced to educate large cohorts of Irish engineers. We describe three separate laboratory classes and one typical team project, all of which serve to provide concrete experiences to students to complement formal lectures and tutorials. Aspects of these various active learning assignments are informed by our research interests and we adopt a research-led method of teaching by exposing our students to our research findings and by encouraging them to understand these findings through their acquired experiences during these assignments. In our paper we attempt to quantify the benefits of this balanced mode of learning over more traditional modes, which rely exclusively on formal lectures and written examinations. Assessment of this module is divided between a traditional written examination (70%) and individual laboratory reports (approximately 15%) and a team project assignment report (approximately 15%). Prior to these elements of concrete experimentation being introduced, this module was assessed solely upon a written examination of material taught via a set of formal lectures.

2. Method

2.1 Laboratory experiments

The concepts learned in the First Year mechanics course are applied to many of the subsequent courses taken by engineering students. A solid understanding of these concepts is essential for the academic success of any engineering student. The combination of both practical and theoretical methods can reinforce knowledge much more effectively than by just learning from the classroom environment. The First Year Mechanics for Engineers course at University College Dublin is an ideal opportunity to use laboratory experiments to reinforce theoretical knowledge since the three laws of motion can be demonstrated with relative ease.

Three compulsory laboratory experiments were designed for the students to take during the semester. These three laboratory experiments are scheduled at different times during the semester, ideally to coincide with the theory being taught in lectures at that time. The three laboratories are not intended to cover all the theory from the course, but they deliberately cover very important core concepts that are essential for the understanding of the course.

Laboratory sessions are given daily to a different student group, and each student group eventually takes the three laboratory sessions. In total, 45 laboratory sessions are delivered, 15 times for each laboratory experiment. In each laboratory session, a maximum of 20 students are present. Four parallel laboratory stations are set up for each experiment; therefore, a maximum of 5 students work on a station at a time.

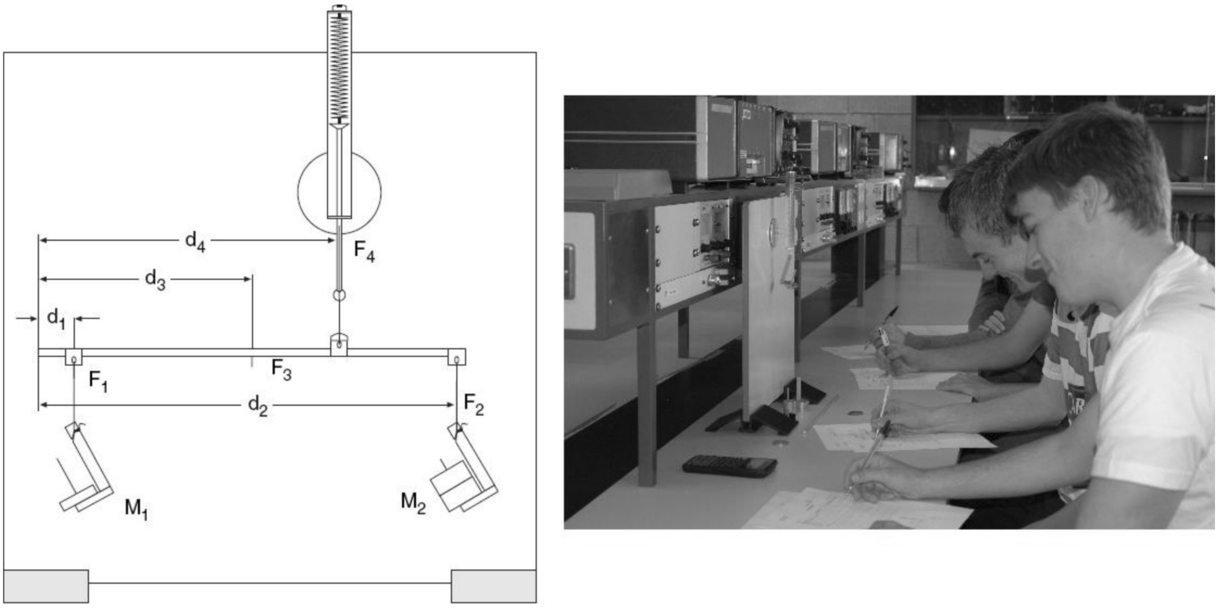

Fig. 1. Rigid body equilibrium laboratory, and first year students at the first mechanics laboratory session.

The first of the three laboratory experiments covers equilibrium of a rigid body. In this experiment, shown in Fig. 1, the student groups are required to assemble a specific system of forces by using calibrated weights and hanging them to a beam which is suspended from a calibrated spring gauge. The students need to ensure that the beam is as close to a certain required orientation as possible. When doing this, they can immediately see how the position of the weights affects the orientation of the beam, and how this also affects the reading on the spring. Once they have achieved the required equilibrium condition, the students then proceed to study the positions of the hanging weights and the spring balance. They need to measure the distances between all the elements that induce forces on the system, and they are then required to draw a free body diagram to calculate the moments and forces in the system and prove the condition of equilibrium.

The second experiment involves the study of friction. Friction tends to be a challenging subject in an introductory mechanics course, as intuition can give misleading ideas of how friction actually works. For example, friction does not depend on the surface area between the materials in contact, but intuition could suggest that it does. This laboratory is intended to clear these misconceptions as well as to explain the difference between static and dynamic friction. Each laboratory station includes a plane which is used to measure the static and dynamic friction coefficient of the plane with respect to different contact areas of the same material as well as different materials. The inclined plane can be tilted to any angle, and weights are attached to a pulley which pulls the object along the plane. Students can observe the effect of how static friction and dynamic friction act by modifying the mass and which pulls the object along the plane and the material of the sliding surface. The students then draw free body diagrams and calculate the friction coefficient. In this experiment, the students are able to isolate the behaviour of static and dynamic friction to facilitate their analysis and understanding of friction (Fig. 2(a)).

The third laboratory experiment covers projectile motion, which in turn explains uniform and uniformly accelerated motion. All of the groups are given a set of ball bearings and a spring launcher which can be set to launch the ball bearings at different speeds and angles. The students are first asked to calculate the initial ball bearing velocity by measuring the ball displacement from a horizontal launch angle. They subsequently measure the angle at which the projectile reaches the maximum displacement at the same level of the launcher and at a level lower than the launcher. In this experiment, students would need to calculate the horizontal uniform motion and the vertical motion of the ball bearing which is influenced by gravity (uniform acceleration). The student then can readily see how the equations for parabolic motion agree with their measurements (Fig. 2(b)).

In all three laboratory sessions, apart from the calculations they are required to perform to analyse the phenomenon in question, they are also asked to analyse their results in more depth. Sources of error are always present in laboratory measurements. The students are asked to identify what sources of error could arise from the measurements they have made.

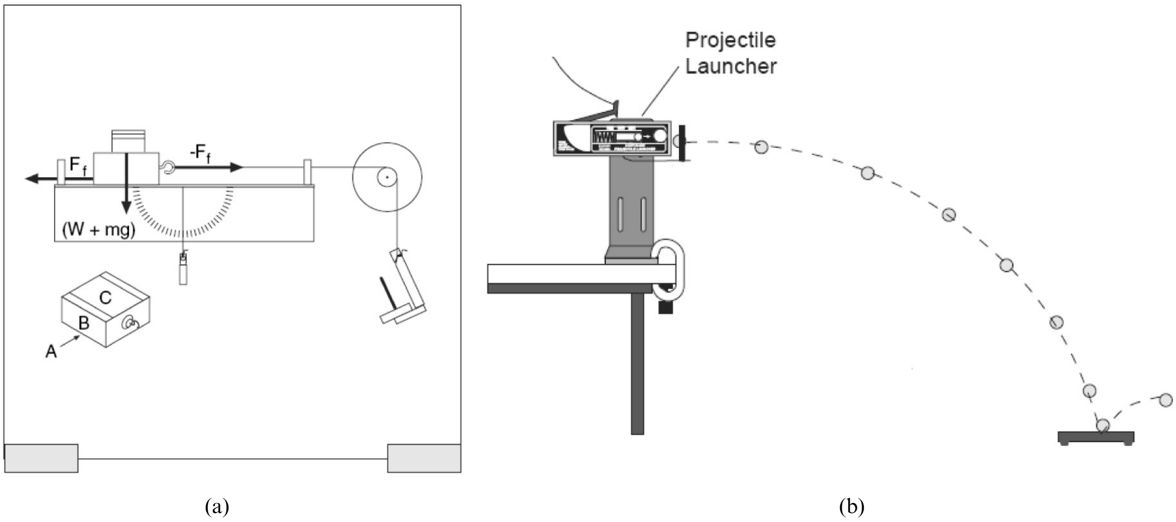

Fig. 2. (a) Friction laboratory setup (the block has sides with different surface areas and materials). (b) Projectile motion laboratory setup.

This is a particularly important point of these laboratory sessions, as high precision measurements of mechanical systems are very difficult to achieve, and differences between theory and practice are always visible. Perfect agreement with theory is not possible; therefore students need to demonstrate their awareness of factors that generate this difference which are inherent to the experiment. This is important to learn at an early stage of any science based career. Limitations in measurement and calculation will always be present, but quality research can still be made by carefully identifying and considering these limitations.

Designing mechanics problems and examination questions for students requires a very solid understanding of the concepts that are needed to solve them, and a good understanding of what concepts need to be reinforced and which are the most challenging for students. With this in mind, each student is asked to formulate one multiple choice question dealing with the concepts involved in each laboratory experiment. This is a good way to encourage students to think about problem solving methods, reinforce their theoretical knowledge and demonstrate their personal understanding of specific concepts. In this manner, students need to think of what variables and concepts are needed to solve basic mechanics problems and understand Newtonian mechanics.

Laboratory reports are required from each student, and these are written during the laboratory period (2 hours each) using a template set of laboratory sheets. The questions are designed so that students will get different answers from each other; this obliges them to perform calculations on their own. Nevertheless, the answers will be relatively similar as they are all solving the same problem. This encourages the comparison of results between students and through this team-based learning they share how they have solved the problem together. Of course, the sources of error and the possibilities of multiple choice questions are numerous, so this part of the report is not expected to be too similar between students. The three laboratory reports account for approximately 15% of the final course grade (ranging from 10–20% in different academic sessions).

2.2 Team assignments

A fairly open design problem with some given constraints is assigned to the class, and they are allowed to solve the problem by any means necessary as long as it complies with given guidelines. The class is randomly divided into groups of up to 5 students which compete against each other to achieve the best solution according to given criteria. Group projects such as these design challenges can be used to further enhance the involvement of the students with the theory learned in lectures, and to encourage their creativity, teamwork, and communication skills, which are very important for any working environment. A friendly competitive environment between the groups is created to further motivate the quality of the results and to encourage each student's interest in the results from other groups. A mechanics problem can be analysed on many levels, depending on the knowledge of the person. A theoretical explanation as detailed as the student's current knowledge allowed was required from the students, to establish the mental connection between theoretical analyses and everyday life. Students were also encouraged to research more advanced concepts personally, in order to enhance

Table 1. Assignment brief for 2008–2009 MEEN 10030

COURSE ASSIGNMENT—PASTA BRIDGE DESIGN CHALLENGE:
Teams of 5 students are challenged to build a single structure of bridge using only pasta and glue. The structure will be freely supported between two tables 1 meter apart. The structure cannot be glued to either of the tables. The structure will be required to support increasingly heavy weights in a lightweight Tupperware box, of dimensions 21cm X 15cm, which will be centred at its midspan.
Marks will be given according to how the bridge will sustain a weight for 10 seconds. Each structure will be ranked according to the radio of weight carried to the weight of the actual structure: that with the largest ratio will be judged the best.
A technical report of no more than five pages is required to justify the design. All students from the group will be expected to contribute to the assignment and should be present at the time of evaluation. Each team member will be given the same grade, which will contribute to the overall assessment on this module.

VENUE:
Level 1, Engineering Building, UCD Belfield, 5:00–9:00pm, Tuesday, November 4th 2008.

ASSESSMENT:
This assignment represents a percentage of the overall marks for MEEN 10030. The breakdown of assessment marks is Technical report (40%) Performance of Structure (60%).

CLARIFICATION NOTES:
'Glue' excludes adhesives which have backing tape (e.g., duct tape).
The total weight of the structure cannot exceed 4kg.

their understanding and analysis of the mechanical phenomena involved in the project.

As an illustrative example, we describe the assignment brief of 2008–2009, which is indicated in Table 1. Students were asked to build a structure made using only pasta and glue. The structure was required to support containers of given dimensions, to which weight was added incrementally (Fig. 3). The main topic in the course dealing with this assignment was trusses and distributed forces. The structure was required to rest freely on two tables at a span of 1 m. The maximum weight of the structure was not allowed to exceed 4 kg. The structures were ranked according to the performance criterion of maximising the ratio of weight carried to structure weight. Students were allowed to use any available combination types of pasta, and any commercially available adhesive. They were asked to deliver a short report where they listed the technical specifications of their structure and justified their design choices. The highest marks were given to the team that built the structure with the best performance criterion. Marks were also given for the consolidated team report. The group project was a percentage of the total course mark (ranging from 10–20% in different academic sessions).

The brief for the project was given during the first month of the academic semester, and the delivery deadline was set for three weeks later. This allowed students to think about the project while they were learning the concepts from the course that were needed to justify their solutions. The projects from all groups were evaluated on the competition/assessment day. The criteria used to evaluate the

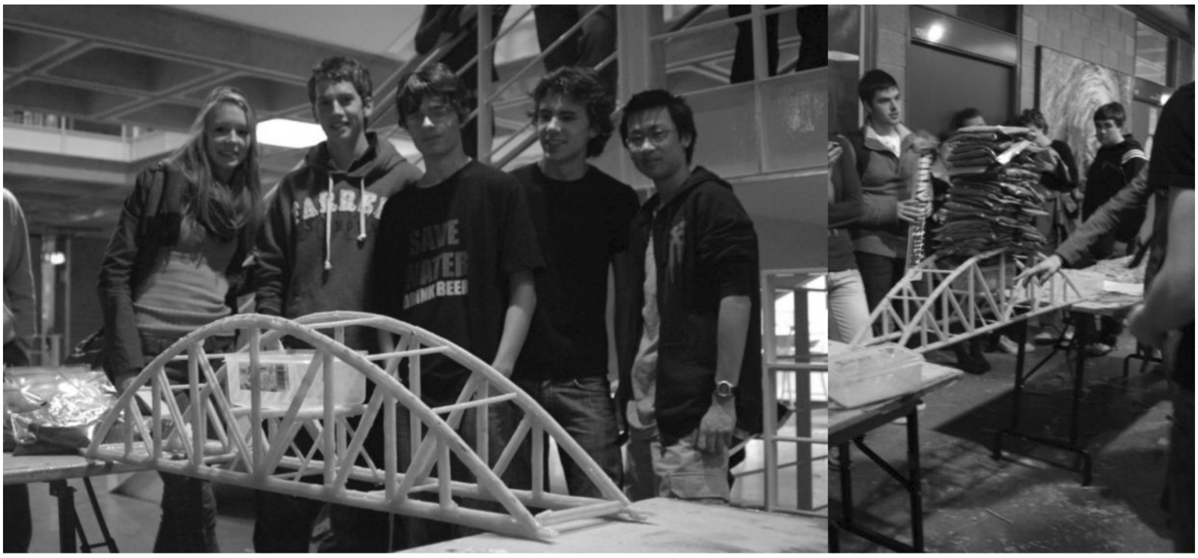

Fig. 3. Winning team for design assignment. Brief was to design and build a bridge weighting no more than 4 kg using only pasta and glue which would maximise the ratio of weight carried to bridge weight. The winning team's truss shown above carried 21 times its own weight.

projects were designed to facilitate evaluation of a large quantity of group projects during a single session (52 groups each of approximately 5 students).

2.3 Involvement of postgraduate students

The application of practical methods in a typically theoretical class requires a significant increase in human as well as physical resources. With proper planning, large groups of students can be organized to achieve effective and efficient laboratory sessions, as well as to execute meaningful and memorable project competitions. A laboratory room that holds twenty students can be used to give laboratories to large groups if the laboratories are repeated frequently.

As part of the postgraduate formation process, postgraduate students in engineering are required to perform Teaching Assistant (TA) duties. These duties expressly do not involve any formal lecturing or examining of undergraduate students. Six TAs can comfortably support the laboratory sessions for this course when they work in pairs. The TAs introduce the laboratory experiment to the students and illustrate how the concepts learned in the experiments relate to lectures, everyday problems and to the particular research the TAs are doing. The research conducted by the TAs is highly diverse, covering a large spectrum of mechanical engineering fields. Some of these fields are manufacturing, biomechanics, computer modelling, accident reconstruction, impact mechanics, and classical mechanics. During the laboratory session, the TAs help the students with any issues they might have during the experiment or questions regarding the laboratory reports they need to deliver at the end of the session.

Even though the postgraduate students are all mechanical engineers, their research backgrounds can differ substantially. The research topics of their PhD theses deal with a wide range of problems from areas as diverse as computational mechanics, impact biomechanics, energy absorption, fracture of composites and materials science. This is a positive aspect of using TAs in laboratory sessions as they can give many different perspectives based on the same concepts when explaining Newtonian mechanics, which enriches the students' experience.

TAs also give tutorial sessions where they prepare sample problems and have the students attempt a solution to the problems before each session. Attendance at the tutorial sessions is voluntary and work done in these sessions is not graded. The TAs then proceed to answer any questions the students might have. TAs also assist in the evaluation of the group projects as judges so as to expedite the assessment process.

2.4 Final year projects

Final Year undergraduate students are required to write a dissertation addressing a given engineering problem. This capstone project should have a high educational value for the student. With this in mind, many final year projects are designed based on current engineering research themes. Postgraduate students play a major role in assisting the undergraduate students and guiding the project to a successful completion. The project would be directly related to the research that postgraduate student is doing, therefore the undergraduate student would get first hand expertise in his/her project. Undergraduate students benefit from this assistance, as they learn skills in engineering and problem solving. The postgraduate students also benefit from this as the work done by the undergraduate student can provide an important addition to their current research; they also acquire useful mentored experience of individual teaching and supervision.

In the past four years, 8 final year students have written their project dissertations with the aid of postgraduate students in our research group. These dissertations dealt directly with ongoing research in various fields, such as computer modelling of impacts, accident reconstruction, human tissue modelling, design and modelling of energy absorbing mechanisms, and material modelling. The students gained skills in the use of high-end equipment, software and analysis techniques used in research. This exposed undergraduate students to the research being done by our research group. In this manner, the students could see how the theory and skills they learn through their undergraduate studies are applied to real problem-solving scenarios. In some instances, these undergraduate project activities led subsequently to a number of publications [21–25].

2.5 Research-led undergraduate education

It can be seen from what has been mentioned previously how mechanical and materials engineering research can be integrated into the undergraduate education process for the mutual benefit of research and education. Current projects in our research group are frequently used as examples during lectures to illustrate the far-reaching scope of concepts that undergraduate students learn in this mechanics course. Postgraduate students communicate the fundamental mechanics principles involved in their research to the undergraduate students through the laboratory sessions, tutorial sessions, group projects and final year projects. Postgraduate students acquire experience of communicating ideas from their research and greater understanding of their own research, as explaining a concept or idea to people unfamiliar with it actually requires a much deeper understanding of the topic than just understanding by oneself.

3. Learning outcomes

Through a research-led teaching philosophy the students are exposed to current research in the laboratory by having interactions between research and teaching activities. This variously involves illustrative demonstrations of fundamental concepts using current research (e.g., mechanics of falls, impact biomechanics, energy absorption, fracture of composites), student internships based in the laboratory, and undergraduate research projects. This pedagogic approach reinforces students' understanding of concepts in engineering science and develops their ability to visualise real-world problems in terms of underlying fundamental concepts. It subsequently empowers them to analyse problems quantitatively and to obtain solutions to physical problems. This approach enhances the quality of teaching to the mutual benefit of both undergraduate and postgraduate students. This significantly enhances the learning experience of very large numbers of First Year undergraduate university engineering students who study Engineering Mechanics. It also provides postgraduate Teaching Assistants (TAs) with valuable opportunities to acquire a rich teaching experience based on research-led methods. Table 2 summarises the specific learning outcomes that are achieved for this module with this mode of delivery and assessment.

According to Bloom's [26] widely regarded taxonomy, human thinking skills and competencies acquired by students can be separated into six distinct categories, namely, *knowledge, comprehension, application, analysis, synthesis* and *evaluation.* Elements of each of these competencies are developed explicitly in this engineering mechanics module. The professional accreditation organisation of UCD's honours degree programme in mechanical engineering is awarded by Engineers Ireland (IEI). They specifically categorise the competencies and learning outcomes of UCD's and all other Irish engineering degree programmes as follows [27]:

(a) graduates must demonstrate the ability to derive and apply solutions from a knowledge of sciences, engineering sciences, technology and mathematics
(b) graduates must demonstrate the ability to identify, formulate, analyse and solve engineering problems
(c) graduates must demonstrate the ability to design a system, component or process to meet specified needs, to design and conduct experiments, and to analyse & interpret data
(d) graduates must demonstrate an understanding of the need for high ethical standards in the practice of engineering, including the responsibilities of the engineering profession towards people and the environment
(e) graduates must demonstrate the ability to work effectively as an individual and in multi-disciplinary settings together with the capacity to undertake lifelong learning
(f) graduates must demonstrate the ability to communicate effectively with the engineering community and with society at large

Prior to this module being introduced in 2006/07, there had been no explicit learning outcomes associated with its predecessor module. The first three of these learning outcomes are explicitly assessed during a written examination by requiring students to construct various free body diagrams and to subsequently solve a range of mechanics problems. The last three learning outcomes, on the other hand, were never easily assessed by the predecessor to this module, but are easily assessed by both the laboratory and project assignment components of this present module.

4. Discussion

So far, the laboratory sessions have been running for five years, after having been introduced in 2006/07. Anonymous survey questionnaires, including those administered by ourselves and centrally within the university, confirm that these are re-

Table 2. Learning Outcomes for module MEEN 10030

On successful completion of this subject the student will be able to:

1. Visualise physical configurations and thereby construct meaningful mathematical models in terms of real materials, actual constraints and the practical limitations which govern the behaviour of machines and structures.
2. Explain concepts of statics and kinematics.
3. Use Newton's laws to express and solve problems in mechanics in mathematical terms.
4. Analyse and interpret laboratory measurements of mechanics experiments.
5. Demonstrate an awareness of safe laboratory practice in the use of a range of laboratory equipment.
6. Work effectively, as a member of a team/group, in the collection, analysis, presentation and reporting of engineering information, adhering to standard conventions for technical reporting but using diverse forms of communication.

Table 3. Evolution of highest and lowest grades over past seven-year period. Figures given in bold correspond to those of the module that had been delivered prior to the introduction of MEEN10030 in 2006/07 (that particular module was known within UCD as MAPH1014)

	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
A+	**28%**	**29%**	**28%**	10%	5%	10%	3%
Fail	**13%**	**16%**	**18%**	23%	13%	24%	15%

garded as a useful improvement and are uniformly well received by the students. It is clearly evident that students have become more confident and enthusiastic about active participation in their education. It has also been noted that students are willing to share their knowledge with each other during laboratory classes. The laboratory sessions are deemed to be an additional opportunity to reinforce concepts learned during lectures and tutorials; they also provide a way to gauge the level of understanding of students, as they are less inhibited about asking questions when they are part of small size laboratory groups. This was seen, irrespective of whether or not students had taken applied mathematics or physics in their pre-university education. The laboratory sessions were designed so that advanced students would have opportunities to clarify doubts that they might have, while simultaneously provide a good foundation for weaker students.

Tutorial sessions have proven to be very successful. Even though attendance at tutorials is not compulsory and the work done at the tutorial sessions is not graded, attendance at tutorials is very high. Tutorial sessions are also scheduled at the start of each morning, when students are most alert; the high attendance rate despite the early starting time shows that students are motivated to participate in the tutorials. Early scheduling also increases the chances that the students come with a high level of enthusiasm. Students regard tutorial sessions as useful opportunities to study and ask questions regarding mechanics problems of a similar nature to those that they might encounter in their exam. Anonymous student survey results show that students find tutorial sessions to be useful for reinforcing their knowledge, as they have a specific opportunity to ask questions on theory or specific exercises that they may wish to solve.

The team project assignment has proven to be extremely popular with students. This was seen by the effort made by all students to construct their pasta structures, many of which produced excellent results. 100% of all student groups participated in this aspect of the course. Students remained even after their own structure was evaluated to see how the work of other groups performed and to see who the winning group was. Anonymous survey results showed great enthusiasm from the students and they recommended that challenges of these types be done for students in all subsequent years.

It is informative to consider the effects on the highest and lowest grades that have been associated with this module and its predecessor module. Besides some rationalisation in syllabus content, the major change that was introduced in 2006/07 was the use of laboratory classes as part of the assessment process and in 2008/09, the further introduction of the use of a group project assignment as part of the assessment process. Table 3 shows that the proportion of students receiving the highest grade or honour possible, i.e., A+, dropped from almost 30% to not more than 10%. Relatively similar proportions of students, approximately 15%, are seen to continue failing this module on the first occasion at which it is attempted. The slightly higher proportions of failing students in years 2006/07 and in 2008/09 correspond to the two years in which assessment changes introduced firstly a component due to performance in laboratory classes and, secondly, a component due to performance in group assignments.

5. Conclusions

There is a significant increase in active student participation in the engineering mechanics module due to the inclusion of laboratory and tutorial sessions and group projects. While attendance records are not taken during lectures, participation rates are typically in the order of 80–90%, compared to 50–60% previously. The First Year Mechanics for Engineers course taught at UCD has been enriched by this increased participation. Students are consulted periodically to confirm their level of understanding and overall satisfaction with the course. The use of practical sessions with the combination of conventional teaching techniques has been popular with undergraduate students. Failure rates appear to have remained relatively static at approximately 20%. This is consistent with the calibre of students entering university remaining high and the academic standards being set within this engineering module also remaining high. The highest grades that have been awarded dropped from almost 30% to no more than 10%. This is not due to a weakening of the calibre of students or a lowering of threshold standards. Instead, it is a consequence of using lecturing and assessment methods that extend beyond solving conventional mathematical problems to rely also on team-based laboratory classes and research-led assignments. This has required more resource-intensive modes of delivery.

The use of research-led methods in teaching has been successful in relating current coursework to actual engineering problems, and the involvement of our research group in teaching has been of benefit for both undergraduate and postgraduate students. Final year projects benefit greatly from the constant contact with postgraduate researchers. High quality final year projects, many of publishable standard, have resulted from the involvement of postgraduate students during the course of the undergraduate students' theses.

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