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An Integrated Approach to the Teaching of Numerical Methods to Engineering Students

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AN INTEGRATED APPROACH TO THE TEACHING OF NUMERICAL METHODS TO EGINEERING STUDENTS

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Abstract

In Dublin Institute of Technology, historically, numerical methods were taught to engineering students using a format of traditional mathematics lectures, to a large class group consisting of students from five different engineering disciplines, complemented by small class tutorials. Assessment was by a single, written exam only.

In order to improve the overall effectiveness of the students' learning experience, it was deemed beneficial to also introduce practical computing classes in which the students would be required to apply the general mathematical methods covered in lectures to discipline-specific examples.

Three different practical computing assignments were devised for the students to undertake, and 20% of the marks for the course were allocated to these assignments. The numerical problems considered were the solution of ordinary differential equations (ODEs) and partial differential equations (PDEs) using the finite-difference method; the solution of first- and second-order ODEs using Runge–Kutta; and the solution of first-order ODEs using Milne-Simpson.

It was hoped that students would find this integrated approach engaging and formative in their understanding of numerical methods and their application to real-world engineering problems. To ascertain if this was the case, an anonymous, online survey of the students involved was conducted, along with a number of interviews of individual students. In addition, a comparison was carried out between these students' grades, and grades from years prior to the introduction of the practical computing classes. The results of both the survey and the grade analysis will be presented in this paper

1.Introduction

There are five Engineering disciplines taught in DIT Bolton Street College, namely Building Services, Civil, Manufacturing, Mechanical and Structural Engineering. The third year class of the Honours Degree of each discipline is taught the same Mathematics course as a single group. In 2005, this subject was grouped together with Computer Programming as a single subject with a break down of marks of 80% and 20% respectively. In 2006, these two subjects were separated and the Mathematics course is now treated as a stand alone subject with 80% of the marks allocated to the written examination and 20% to continual assessment.

The Mathematics course covers the following topics; Calculus, Eigenvalues and Eigenvectors, Fourier Series and the approximation of ordinary differential equations (ODEs) using the Runge Kutta, Milne Simpson and finite difference methods. This course incorporates engineering examples from the last three topics on this list. Two of the six questions on the terminal written examination relate to these three topics.

In the Mathematics course, the students are taught how to implement the numerical methods with pen and paper. For example, a typical exam question on the Runge Kutta method requires the student to apply the method correctly to a given problem for a single iteration. While this is an essential step in understanding how the method works, it is necessary to implement the methods on computers to appreciate the full applicability of the methods to real world problems. In the 2005-06 year, the students were only given a single assignment to implement on a spreadsheet. Following the semesterization of the course in 2006, it was decided to introduce a practical laboratory class to provide the students with a comprehensive course on the application of these methods to real engineering problems. This course is allocated the 20% for continual assessment.

The primary aims of the course are:

1. To demonstrate to the students that numerical methods can be effectively applied to solve real world problems encountered in their specific discipline.
2. To equip the students with the skills to effectively implement the numerical methods on spreadsheets and Math lab.
3. To enable the students to incorporate these techniques in their final year project and possibly pursue post graduate studies in this area.
4. To instill a sense of confidence in the students that they will be able to use these methods in the workplace in their professional careers.

After the completion of the course students were asked to complete an individual survey on WebCT. The purpose of this survey was to provide valuable feedback to staff as to student's perceptions of this learning methodology.

2. STRUCTURE OF THE COURSE

The two hour lab class is run over one twelve week semester. In a typical week, the student is given a handout outlining the background to a specific engineering problem and the development of the numerical solution is presented. Typically, the handout includes a step-by-step set of instructions on how to implement the numerical solution on a spreadsheet (or on Math lab). The instructor typically gives a short 15-20 minute presentation outlining the problem and the students then proceed to solve the problem during the remainder of the class.

2.1 Course Content

A sample of the problems covered in the weekly classes is given here.

Falling Parachutist

A parachutist jumping out of a plane is subjected to a downward gravity force and an upward drag force which is a function of the speed of the parachutist. The parachutist will accelerate until the two forces are equal and will then continue to fall at a terminal velocity. The designer of the jump suit can reduce the terminal velocity by using material with a higher drag coefficient. The students model this problem on a spreadsheet by approximating the equations using a first order Runge Kutta method and produce a graph of the velocity against time.

Swinging Pendulum

The students set up a second order Runge Kutta approximation to the differential equations on Excel and plot the position and velocity of the pendulum. The students then compare the numerical results to an analytical solution formulated by assuming that the initial displacement is small. They then examine the divergence of the two solutions as the initial displacement is increased and the value at which the analytical solution becomes invalid may be determined.

Vibrations of an Instrument

Cockpit instruments in a helicopter are typically inserted into a rubber mounting to minimize the effects of vibration on them. The behavior of the rubber mounting can be treated as a spring dashpot system. The students create a Runge Kutta approximation of the system in Excel to determine the resonant frequency. Variations of this example include the modeling of the vibrations of a fan on a mounting for Building Service engineers and the vibrations in tall buildings during earthquakes for Structural engineers.

Deflection of a Beam

The finite difference method is used to model the deflection of a statically determinate simply supported beam under different loading regimes. The Structural and Civil groups also modeled a statically indeterminate propped cantilever for which an analytical solution is not available.

Heat Transfer Problems

The finite difference method is applied to a number of one dimensional heat transfer problems. The Building Services group models the heat transfer through walls with different composite materials. The model is used to examine the effect of varying the thickness of insulation under time varying external temperature conditions. The Mechanical and Manufacturing groups model the heat transfer in a nuclear rod with internal heat generation.

2.2 Student Assessment

Each student is assessed on three assignments which are based on the weekly examples. In order to avoid plagiarism, the assignments are individualized for each student. In the beam assignment, ten different types of beam configurations were listed and six different loading conditions were created for each one, giving a total of sixty individual problems. These were randomly assigned to the students. Thus in the largest grouping of sixty Structural students, only six students solve the same beam arrangement.

2.3 Student Survey

As stated above an online questionnaire was filled in by a sample of 65 students who completed the courses. Details of the questionnaire and the student responses are listed below.

The questionnaire consisted of twelve questions, all multiple choice, presented on WebCT. Sixty five students completed it. The student's responses to the questions are listed below.

1. It was enjoyable to learn about Numerical methods in a practical computing class.

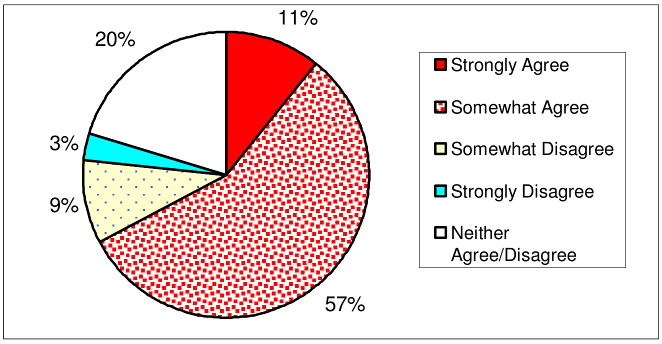

Fig 1. Enjoyment of the Course

The result was reasonably positive with a total of 68% of the students enjoying the course. Only 12% expressed dissatisfaction with it.

2. The practical classes improved my understanding of the application of Numerical Methods (as taught in the Maths class) to engineering problems.

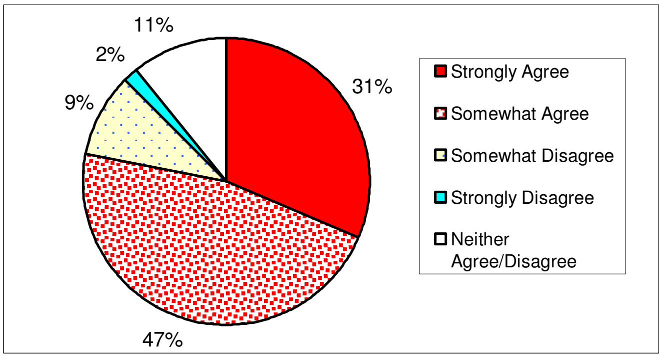

Fig 2. Applicability of Numerical Methods

Seventy eight percent of the students responded positively to the statement and only one student strongly disagreed.

3. I would feel confident in applying the techniques learned in a work situation.

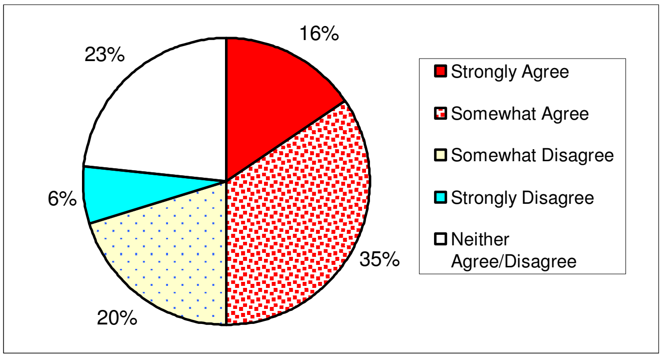

Fig 3. Student's Confidence in the Use of the Methods

Just over 50% agreed that they would be willing to use the techniques learnt in their careers. Just over one quarter of the students disagrees with the statement and one quarter expresses no opinion. A more appropriate question might be "Would you consider using numerical methods in your final year project, if it was possible?"

In the second series of questions we tried to determine the components of the assignments in which the student found the most difficulty.

4. In the Runge-Kutta assignment, I found it particularly difficult to figure out how the variables used in my problem (e.g. t, u, v) were related to the variables (x, y, z) used in the examples in Maths lectures.

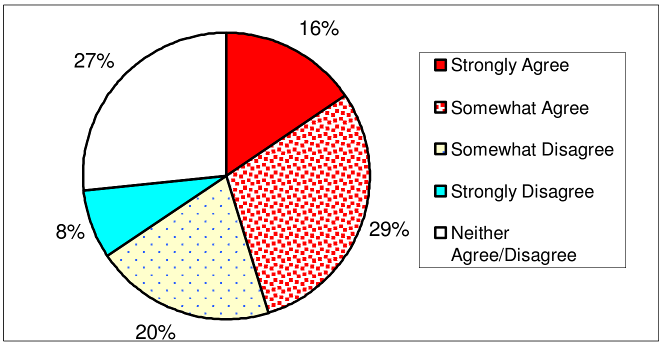

Fig 4. Problem Conceptualization

45% of the students found difficulty in adapting the general methods as taught in the Mathematics class to problems with different coordinates. The instructors observed this problem as they assisted the students with their assignments.

5. I found it difficult to set up the numerical model for the problem.

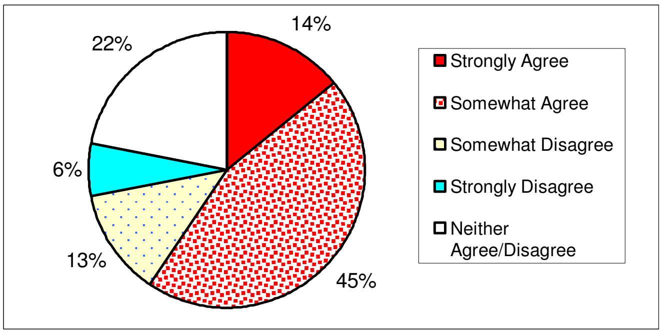

Fig 5. Difficulty With Development of Numerical Scheme

Once again, a large number of the students (60%) find the process of applying relatively simple numerical techniques to real problems to be difficult.

6. Having figured out how to solve the problem using the appropriate numerical method, I found it difficult to implement the solution on Excel.

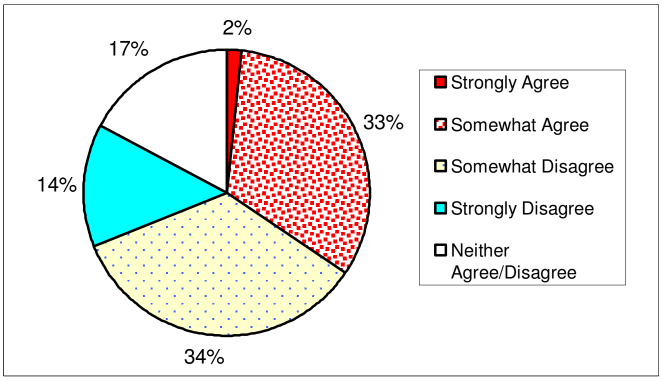

Fig 6. Implementation on Excel

It is not surprising to see 48% of the students disagreeing with this statement as they are very familiar with the Excel package.

7. I found it difficult to implement the Runge Kutta method on Matlab

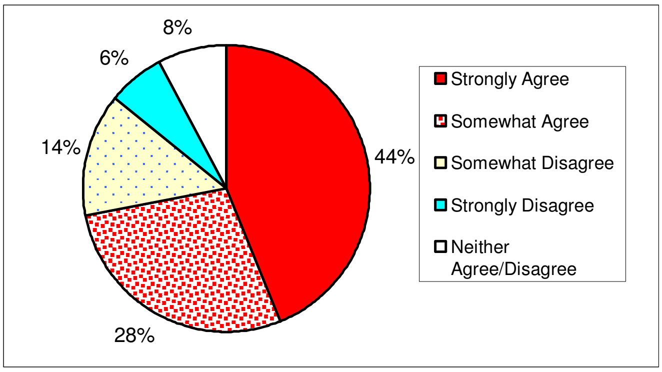

Fig 7. Implementation on Math lab

72% of the students found the Matlab package to be difficult to use. This is understandable as it is the first time they have encountered it.

Finally, in an effort to determine the potential benefits from the applied course, five more questions were asked.

8. Doing the examples in the practical computing classes and completing the assignments was very helpful in understanding how the techniques taught in the Maths class can be applied to real engineering problem.

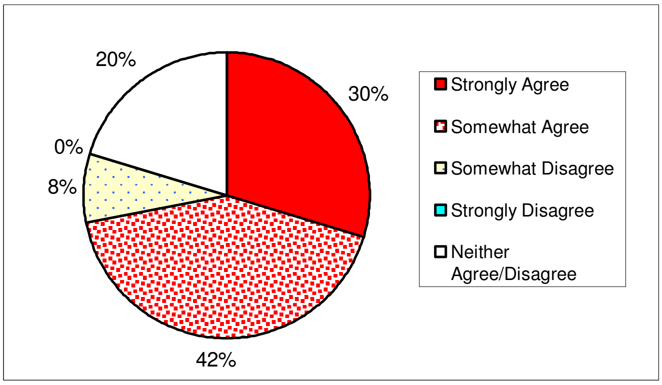

Fig 8. Application to Engineering Problems

A similar question to Question 2 with similar results. The results show 72% in agreement and only 8% somewhat in disagreement.

9. Practical computer classes should be integrated with Maths classes in earlier year.

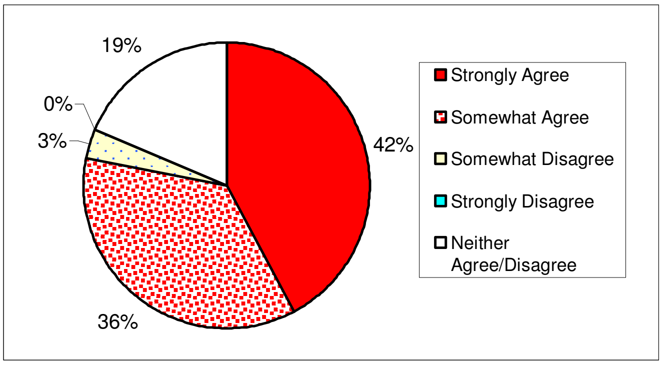

Fig 9. Integration in Earlier Years

78% of the students agree that practical computer classes should be integrated with the Mathematics classes in the previous two years.

10. I liked the format of the practical computing class (i.e. completing an exercise after a short lecture explaining the background to the given problem).

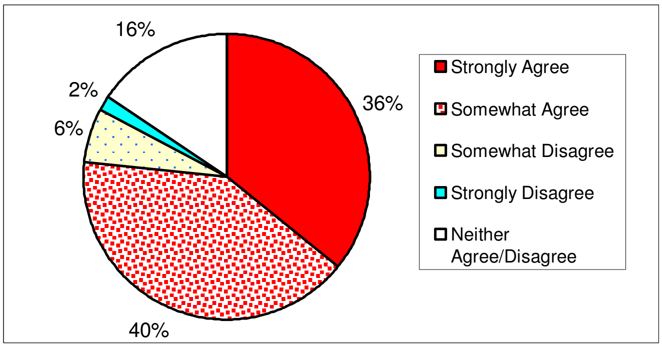

Fig 10. Format of Class

A positive result in which 76% of the students were content with the format of the class.

11. The range of examples used was interesting.

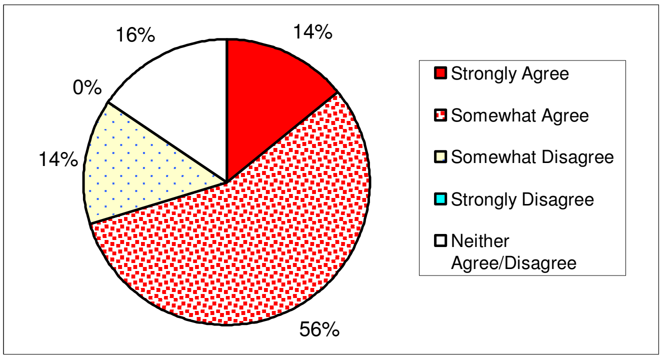

Fig 11. Range of Examples

70% of the student found the range of examples to be interesting with only 14% in disagreement.

12. The tutorial handouts were easy to follow.

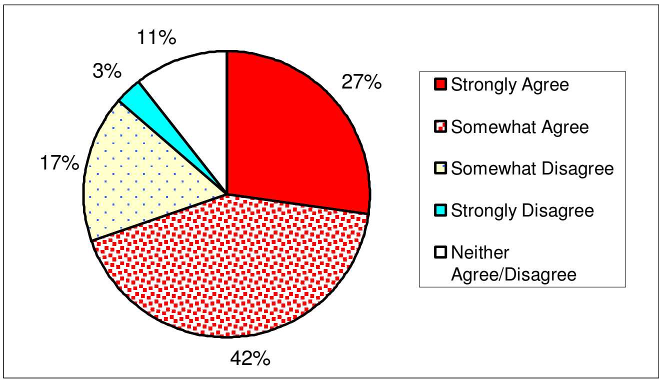

Fig 12. Quality of Tutorials

69% of the students were content with the layout of the tutorials.

2.4 Analysis of Examination Results

A simple analysis was carried out to compare the marks for the Runge Kutta/Milne Simpson and the Finite Difference question before and after the course was introduced. The marks for two of the groups show a significant improvement in the results for the Runge Kutta question. It will be possible to carry out a more detailed analysis when the results from two years are available.

Topics	Runge Kutta/Milne Simpson			Finite Difference		
Question Discipline	Q5 2006S	Q5 2007 Semester1		Q6 2006S	Q6 2007 Semester1	
Civil	63_{11}	89_{14}		75_{16}	82_{14}	
Structural	51_{26}	90_{47}		80_{46}	79_{47}	

Note. The subscript refers to the number of students who attempted the question.

2.5 Student Interviews

A series of short informal interviews were carried out with ten students from the different disciplines. Some of the key recommendations are listed below.

- More work is required on developing discipline specific problems for some of the groups

- Better coordination of sequencing of topics. i.e. the first Runge Kutta tutorial should be completed in the same week that the topic is covered in the Mathematics lecture.

- More tutorials on Math lab are required

3. Conclusions

The results of the survey and the interviews confirm that the examples used in this course clearly demonstrated to the students that numerical methods can be effectively applied to solve practical problems related to their engineering discipline.
The students did find this work challenging and had difficulties with each stage of the work. The students were well versed in the use of spreadsheets but more time needs to be dedicated to developing their skills with Matlab.

Most of the feedback pointed to the students being content with the format of the classes and the handouts. However, some of the groups complained that they weren't content to complete examples not relevant to their specific discipline and more work is needed in developing discipline specific examples.

The positive effect of the course on the average mark on the Runge Kutta question would indicate that it would also be beneficial to expand the course to include practical examples on the Eigenvalue, Eigenvector and Fourier series topics.

The students need to be encouraged to incorporate these techniques where appropriate into their final year projects by the relevant supervisory staff in their departments. The Mechanical and Building Service's departments have been proactive in developing the student's skill sets in this area and have introduced full modules in Computer Modeling. The development of this knowledge base will enable the college to recruit more students into the postgraduate study related to computer modeling.

In conclusion, the course has proved to be a popular success with the majority of the students and it has proved beneficial to integrate practical computing classes with Mathematics classes. The students have clearly indicated that they would like to see similar classes introduced in earlier years.