TEACHING ELECTROMAGNETICS AT UNDERGRADUATE LEVEL AT MASSEY UNIVERSITY - MATHCAD AIDED APPROACH

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ABSTRACT
Mathcad is used in the teaching of Electromagnetics to make mathematical aspects of the subject more interesting, easier to understand and more user friendly. This paper presents examples of the application of Mathcad to the teaching of Electromagnetics. The students' responses show that Mathcad helps them to understand the subject and it enhances their learning.

KEYWORDS
Electromagnetics, education, Mathcad, computer based learning, Laplace's equation, B-H characteristics.

INTRODUCTION

Electromganetics is the most mathmatically intensive course, or sequence of courses, in the undergraduate educational experience. Our course is an in-depth study of the applications of Electromagnetics in modern engineering, the course includes selected aspects of vector algebra, magnetostatics, conductors, insulators, Poisson's and Laplace's equation, transmission lines, time-varying fields and Maxwell's equations. Other topics included in this subject are wave propagation, wave guides, solution of waveguide equations and their applications, and microwave devices. This is a core course for the 3rd year Information and Telecommunication Engineering students at Massey University, New Zealand. However, these students experience great difficulty with the mathematical part of the subject due to inadequate mathematical background.

Electromagnetics is a strongly mathematical subject with very important practical applications. The comprehensive material required to be discussed at this level is complex and wide ranging. Moreover this subject matter cannot be trivialized without seriously compromising its integrity. Electromagnetics courses are seldom popular because many concepts taught in the course require the students to be able to think in abstract multi-dimensional space. Students lacking this natural ability find the subject abstruse and as a result uninteresting and difficult to learn. Many authors have augmented the conventional textbook presentations [Hayt, 2001; Ulaby, 2002; Kraus and Fleisch, 1999; Edminister, 1995] by introducing computer assisted learning to circumvent this problem. Applications have been designed to assist students to visualise electric and magnetic fields and to better appreciate the time varying nature of the phenomena described. The teaching of transmission line theory has benefited from the development of animation software displaying incident and reflected waves on a line [Faria, 2004; Trueman, 1999; Hoole, 1993]. Magnetic field mapping software has been used to illustrate the importance of magnetic shielding in high frequency applications [Hoburg, 2000]. Computer based simulations have been developed to illustrate the important practical applications of electromagnetics and to show how the theory can be used to solve practical problems [Beker, Bailey and Cokkinides, 1998]. Indeed many graphical visualization packages are available which assist student appreciation of the applications of the subject without the prior necessity of mastering the underlying mathematics

[Coren, 1993; Lyvers and Horowitz, 1993; Elsherbeni, Kajfez and Hawkes, 1993], in the expectation that once the student has been convinced of the practical utility of the subject he will be stimulated to learn the theory.

The rapid reduction in the cost of computers in the last decade has made them very affordable and many university students now own laptop computers. To sustain interest in the education process and to fully utilise the computer literacy of the students, it is essential to reinforce the engineering education curriculum with computer-aided teaching tools that are interactive as well as educational. For these reasons computer based teaching approaches, using some computational tools, have been introduced and recently a mathematical software package, Mathcad has been introduced to enhance the teaching of the rigorous mathematical parts of electromagnetics.

DESCRIPTION OF MATHCAD

Mathcad is the industry standard technical calculation tool for professionals, educators, and college students worldwide. Mathcad is versatile and powerful as a programming language, yet it's as easy to learn as a spreadsheet. Also, it is fully wired to take advantage of the internet and other applications we use every day [13]. Mathcad is a general purpose tool with a user friendly Windows interface. Fig.1 shows the blank worksheet of MathCad. The students can use them to solve just any math problem, symbolically or numerically. Everything including text, equations, graph, pictures and drawing can be placed anywhere around the worksheet and it appears on the document as it would in a text book. But the basic difference is that the equations which are written on the worksheet are working equations, which means the results and graphs change whenever the input changes. For these reasons Mathcad is being used in many places for teaching electromagnetics [Delyser, 1995; Delyser, 1996; Nigim and Delyser, 2001].

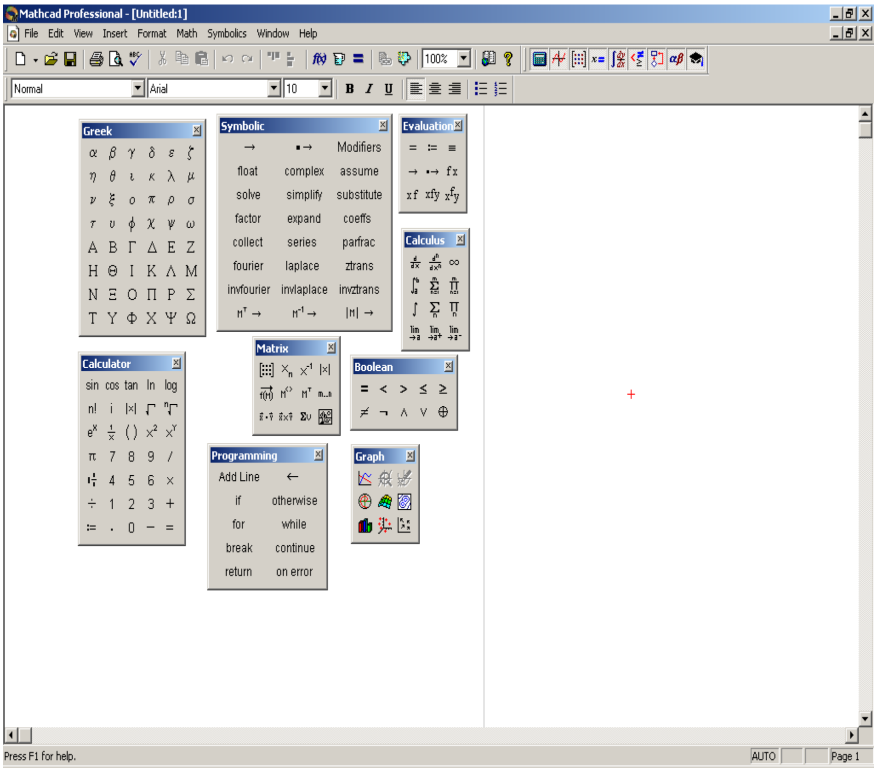

Figure 1. Blank Mathcad worksheet

DESCRIPTION OF THE COURSE

Electromagnetics is a core 3rd year subject, the teaching programme comprises 3 hours of lectures, one hour of tutorial and 2 hours of laboratory work each week and spans 13 weeks. The lectures and tutorials are delivered in the standard lecture format using whiteboard, OHP and PowerPoint presentation. The mathematical part of the course is extensively covered during the lectures and tutorials. Although computer software packages such as FEMLAB (Finite Element Software package) and Mathcad are used during lectures, usually students do not get the opportunity to use these applications during lectures but they do during laboratory time. Half of the laboratory sessions (7 sessions) are devoted to virtual laboratory studies(reference) in which students use FEMLAB and Mathcad extensively. The total laboratory work accounts for 25% of the total grade of the course; the virtual laboratory accounts for 12.5%. So the importance of the computer software packages such as FEMLAB and Mathcad is enormous. Even though our use of Mathcad is recent the response of the students show that they really appreciate it's usefulness for the enhancement of their learning.

USE OF MATHCAD FOR TEACHING ELECTROMAGNETICS

A graphical user interface (GUI) approach has been adopted to make the learning more interesting. The extensive use of Mathcad is encouraged during the laboratory sessions where each student can access an individual computer to work on. The theory and problems of each topic are available to students as shown in Fig. 2. The students select the topic of interest, once the topic is selected then it goes to another window as shown in Fig. 3. This worksheet specifies the problems. The expanded view for a particular problem of Fig. 3 is shown in Fig. 4. The student can start a new worksheet to solve the problem his way. If he has difficulty he may access the solution by clicking the "See the Solution". The problem has been solved in that worksheet as shown in Fig. 5.

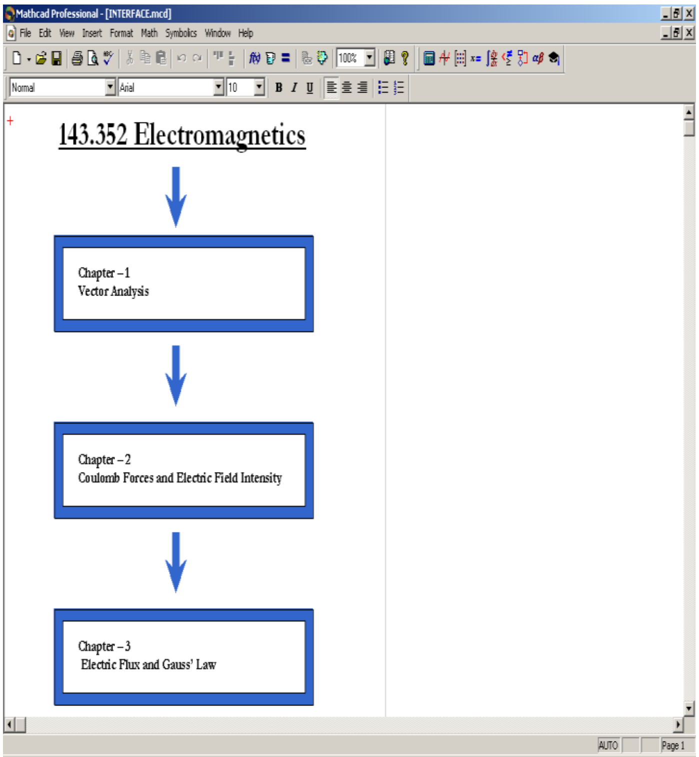

Figure 2. Mathcad worksheet prepared for teaching

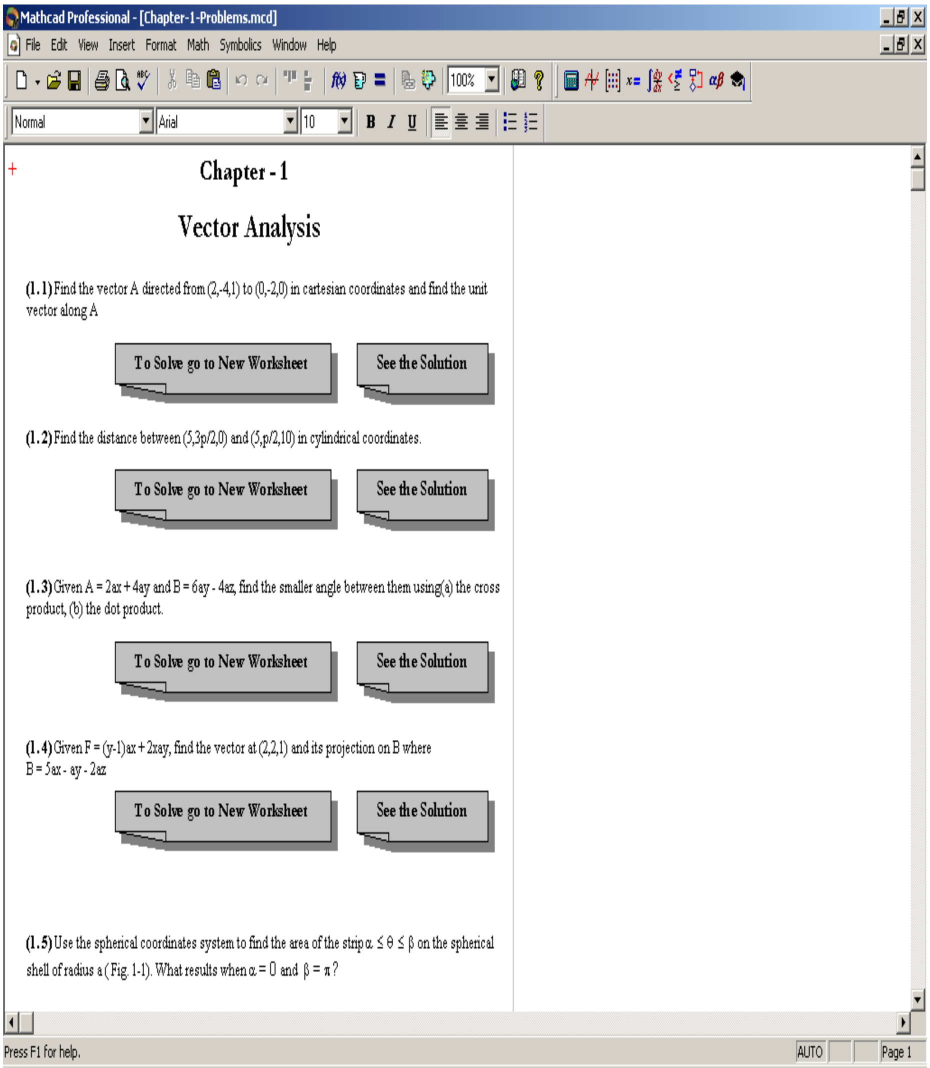

Figure 3. Chapter-1 solved examples and exercises

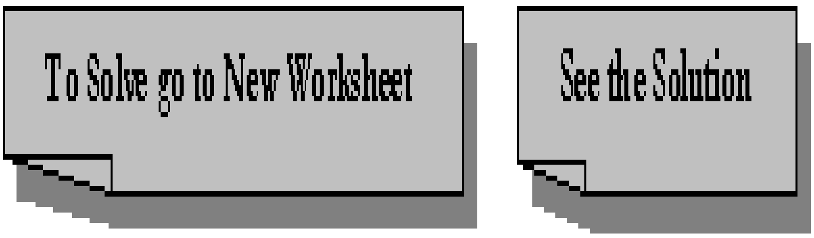

Figure 4. Expanded view of Fig. 3

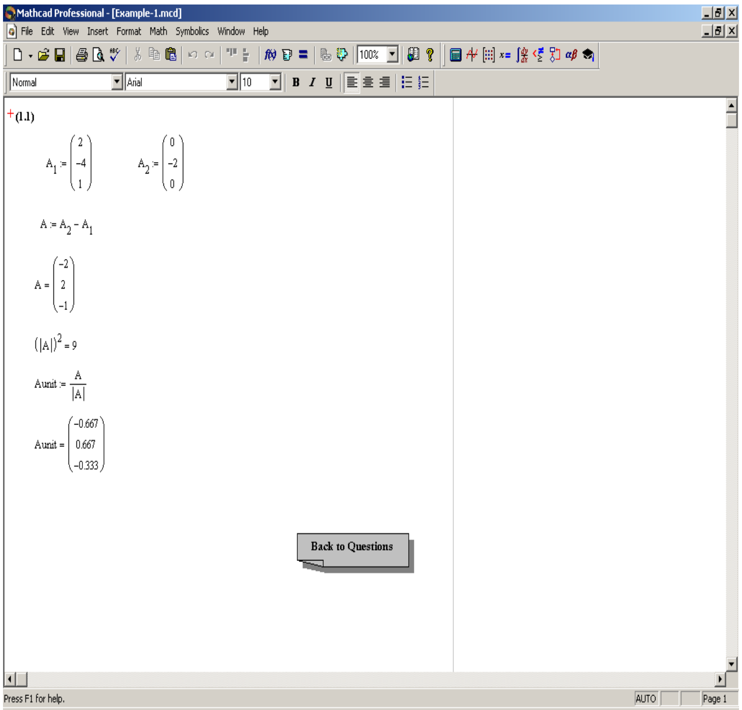

Figure 5. Solved Example in Mathcad

Fig. 7 shows the working worksheet containing the analytical solution of the Laplace's equation for a typical situation as shown in Fig. 6. The graphical solution of the Laplace's equation is shown in Fig. 8. The students can change different parameters and see the effect on the graph instantaneously. This is not very simple to implement in practical laboratory.

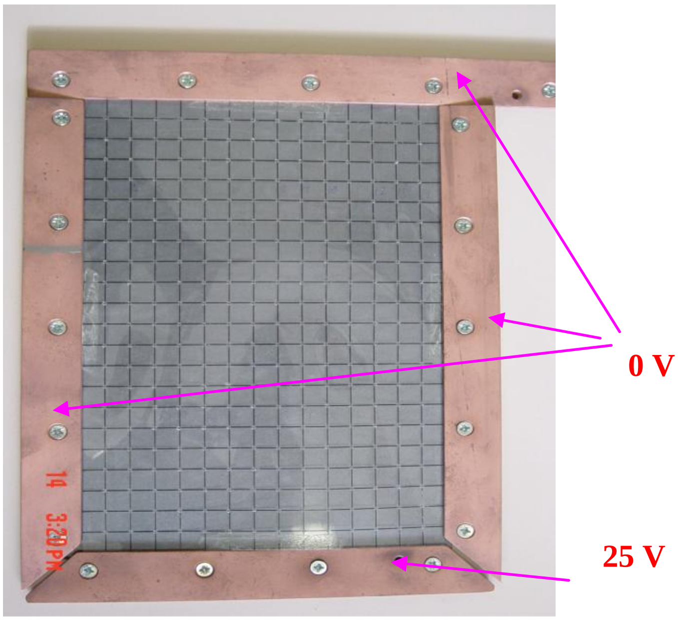

Figure 6. Model for the solution of Laplace's equation

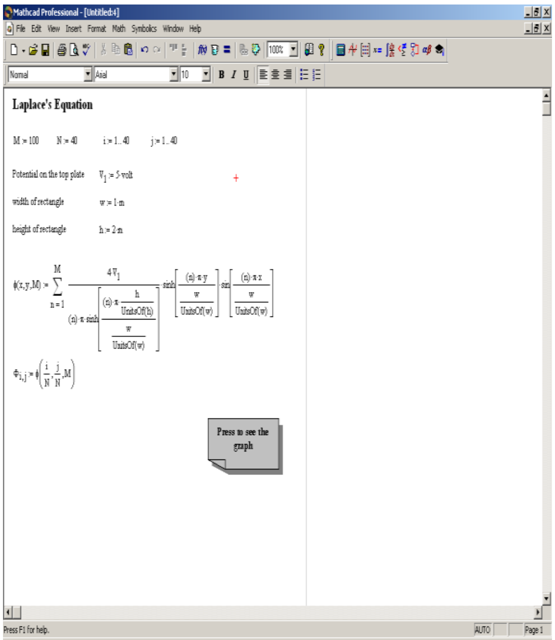

Figure 7. Mathcad worksheet for the analytical solution of Laplace's equation

The use of Mathcad is explained for another interesting problem. Fig. 9 shows the experimental apparatus for the determination of B-H characteristics of ferromagnetic materials. The Mathcad worksheet to obtain the analytical solution is shown in Fig. 10. The analytical solution is based on the representation of hysteresis loop by two curves W_1 and W_2 (equations 1 and 2). The values of the constants are chosen to fit different materials.

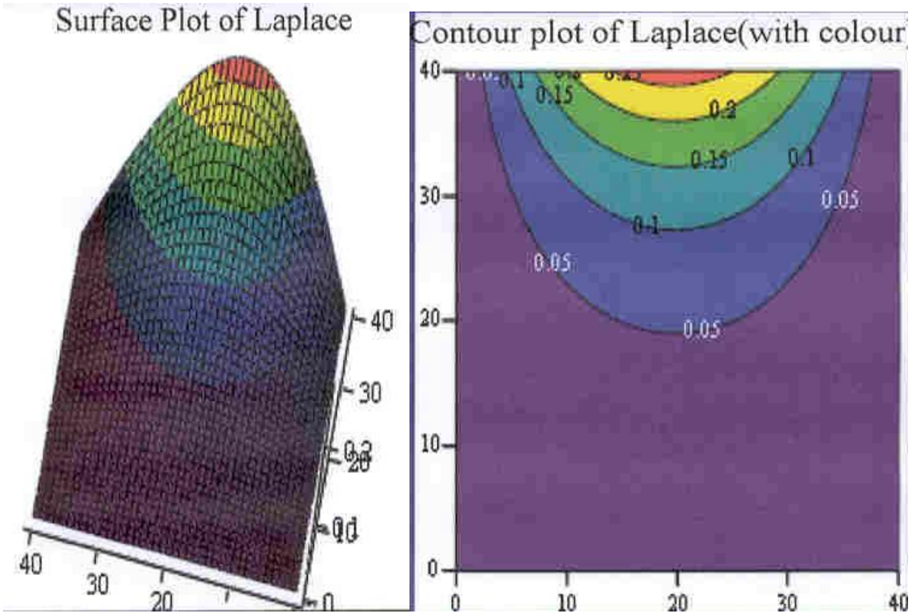

Figure 8. Surface plot and Contour plots of Laplace's equation

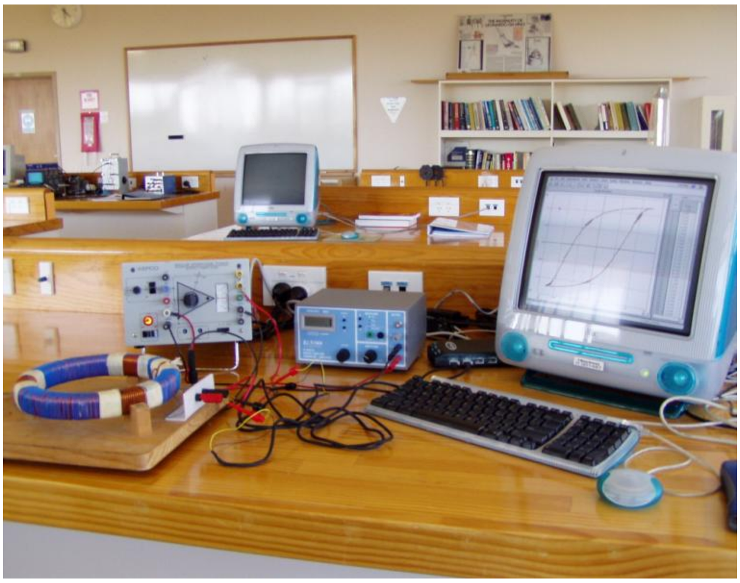

Figure 9. Experimental apparatus for B-H characterisation of magnetic materials

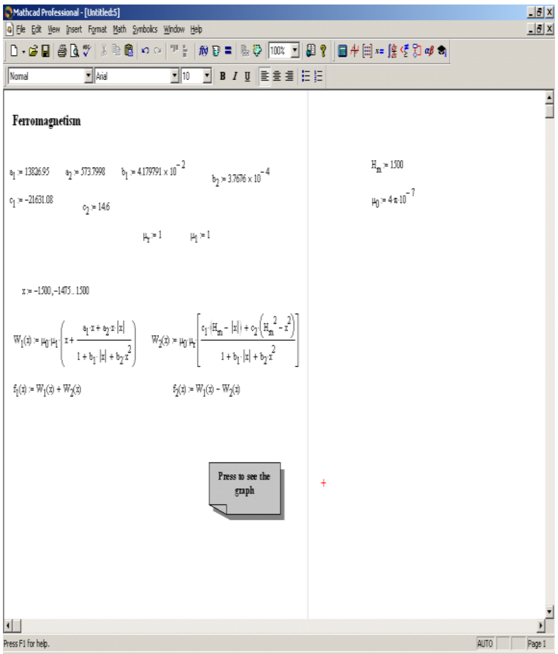

Figure 10. Mathcad worksheet for the determination of BH Characteristic of magnetic material

Six constants a_1, a_2, b_1, b_2, c_1 and c_2 are used to define the functions W_1 and W_2 and they will be different for different materials. The curves W_1 and W_2 are expressed as a function of magnetic field strengths and are given by-

$$W_1(x) = \mu_0\mu_1\left(x + \frac{a_1 x + a_2 x|x|}{1 + b_1|x| + b_2 x^2}\right) \qquad (1)$$

and

$$W_2(x) = \mu_0\mu_1\left(\frac{c_1(H_m - |x|) + c_2(H_m^2 - x^2)}{1 + b_1|x| + b_2 x^2}\right) \qquad (2)$$

where x is the variable used for magnetic field strength. H_m is the maximum magnitude of the magnetic field strength. The B-H loop is obtained by adding W_1 and W_2 for decreasing field strength and subtracting W_2 from W_1 for increasing field strength. Based on this the hysteresis loop is shown for a typical ferrite in Fig. 11. Many other examples have been developed to assist students learning.

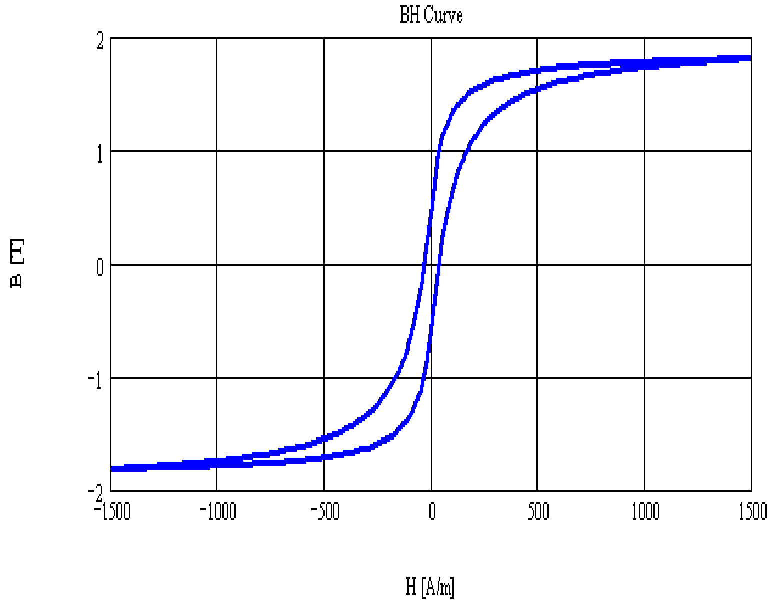

Figure 11. B-H characteristics obtained using Mathcad

OTHER FEATURES OF MATHCAD

In this paper a few examples of the use of Mathcad to teach electromagnetics have been presented. The capabilities of Mathcad are ofcourse much higher that that described in this paper. Mathcad can be very easily used for much more complex problems such as propagation in anisotropic material, reflection and refraction of plane waves in layered media etc. Mathcad results, documents, graphs can be copied directly to word processors. Conversely, text from word processor, drawings, and graphics can be copied on to Mathcad to improve the document. It has the computational power to be used for high performance research problems. The extended features are to enhance Mathcad's functionality by bringing the feature sets of other applications into Mathcad worksheet and expand the usefulness of other programs by interfacing with Mathcad.

STUDENTS RESPONSE

The usefulness of the Mathcad software for the enhancement of students' learning was surveyed with the help of the following questionnaire. Questions 1 to 4 were scored on a 5 point scale, 5 implying very useful, 1 not useful at all.

Questionnaires:

5 – Very useful 1 – Not at all useful

1. What do you think about the usefulness of Mathcad?
   1 2 3 4 5

2. Were Mathcad tutorials interesting?
   1 2 3 4 5

3. Have Mathcad tutorials helped your understanding of the subject?
   1 2 3 4 5

4. Has it enhanced your learning?
   1 2 3 4 5

5. Should be continued?
Yes No

6. Any other Comments

The response of the students for question#1 to #4 are shown with the help of figures 12 to 15. It is seen that the majority of the students like the Mathcad based learning environment, find it interesting and believe that it helps to enhance their learning. Since it is the first time that it has been introduced in the course curriculum and the students need to learn a new software, it will take some time for all students to fully appreciate the usefulness of the software. In response to question#5 all the students agreed that it be continued. Because of this popularity the Mathcad based learning will be continued and additional development work will be undertaken to add more interesting experiments.

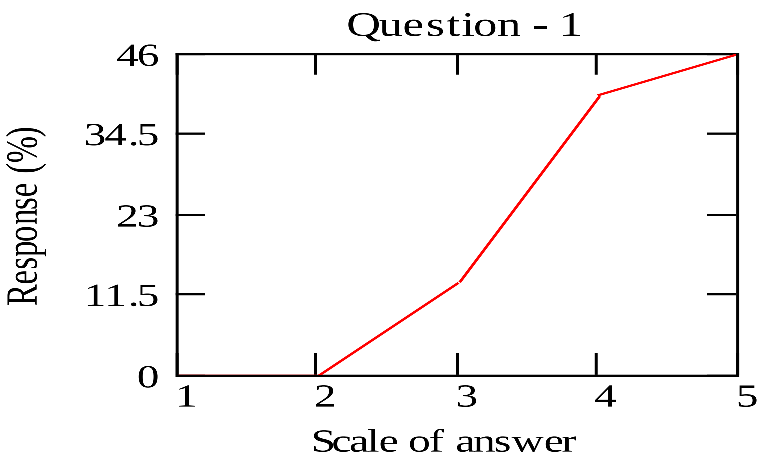

Figure 12. Response of question#1

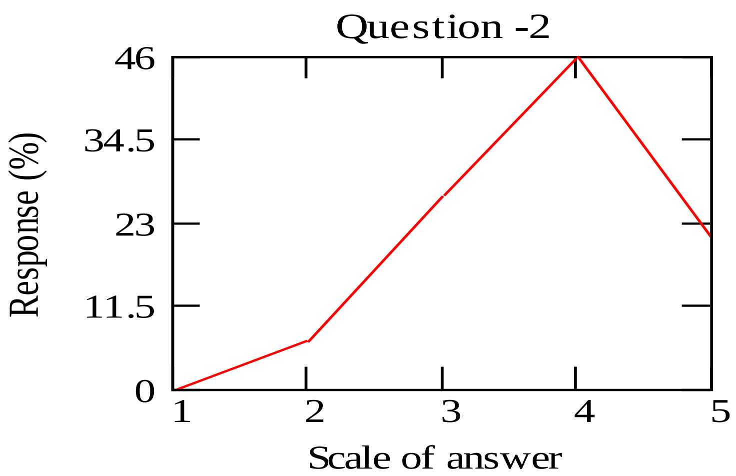

Figure 13. Response of question#2

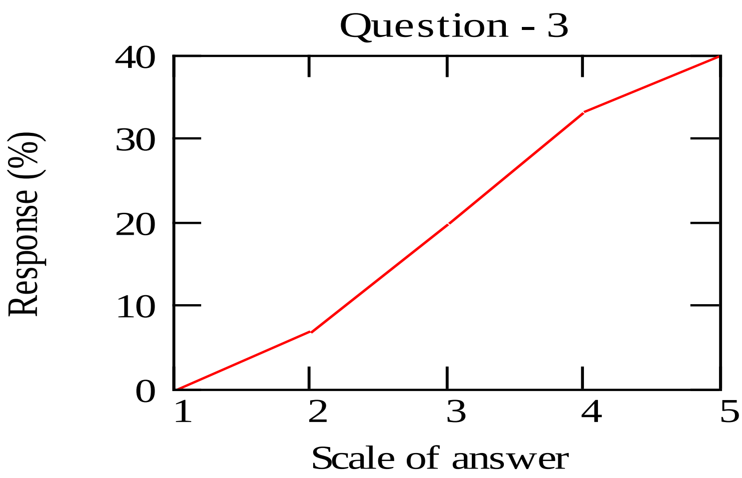

Figure 14. Response of question#3

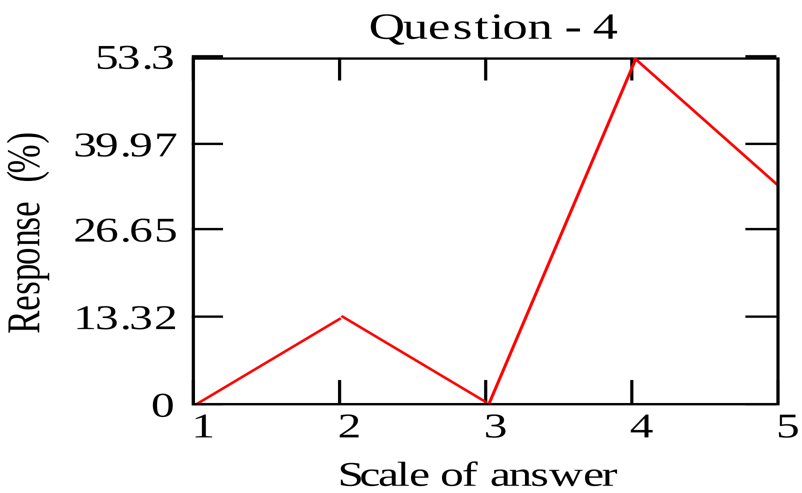

Figure 15. Response of question#4

CONCLUSIONS

This paper has described the use of Mathcad software for the teaching of electromagnetics at Massey University, Palmerston North, New Zealand. Some development work has been carried out using the software and introduced in the laboratory. Individual students get access to the software and carry out virtual experimental work. The response of the students shows that the use of Mathcad has definitely enhanced their learning of the complex subject. The development work will be continued and more experiments will be carried out in the coming year.

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