19 TEACHING STRATEGIES AND METHODS FOR STIMULATING THE INVENTIVE ABILITIES OF ENGINEERING STUDENTS

V. BERINDE
Department of Mathematics, University of Baia Mare, Baia Mare, Romania

Abstract

The aim of this paper is to present some basic principles and strategies for developing the creative thought and inventive ability of engineering students. These principles and strategies can be introduced inside or alongside conventional lectures and can be adopted to form a style of work at any problem solving session in class. This style of work consists in a gradual questioning and answering on the main ideas, notions and facts involved in the given problem, which is in fact the typical working behaviour of any researcher. Our approach is directed mainly at the engineering mathematics and it consists in shaping metacognitive skills and inventive abilities by training students to learn to solve problems in a creative manner. Such active and creative learning can be adapted to various other technical and non-technical subjects in the engineering curriculum.

A partial evaluation of the application of this approach to the non-ferrous metallurgy, electromechanical and mechanical engineering programmes of our university is also given.

Key words: active learning, creative teaching and learning, case studies, problem based learning, modelling steps.

1 Introduction

A problem which faces the engineering educator today is to give an adequate answer to the continuously increasing technical, economic and ecological needs of industry

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and society and to ensure the development and improvement of the education and training of engineers by adapting it to these needs. In the contemporary technical world we especially need good engineers, but a twenty-first century engineer will be a competent engineer if and only if he can be an inventive engineer.

We are concerned here with an attempt to form and develop specific and general creative and inventive skills and abilities by means of mathematical courses. There are, of course, conflicting opinions concerning the position of mathematics in relation to other technical or non-technical subjects in the engineering curriculum. There are many people involved in engineering education who consider that in the contemporary world - when computers are intensively used in teaching and education- mathematics is not necessary or not as important as before in the engineering curriculum (see references) and that consequently it may be replaced by appropriate software packages.

In our opinion, teaching mathematics as well other non-technical subjects to engineering students is necessary not only for its importance at certain levels of various technical subjects, but also as an intellectual process. However, some European universities of technology report that engineering faculties have plans to decrease or have already decreased the number of hours of mathematics in the last five years. The effect of this change will be felt in the future.

In our opinion, mathematics still forms a significant part of engineering degree courses because mathematics develops not only manipulative skills but can be seen as a vehicle for creative and analytical thought alongside its role in developing logical thought. Educators must therefore be convinced of the importance of encouraging students to regard mathematics as a natural part of their package of engineering skills, as a fundamental engineering subject, in spite of the increasing penetration of computers and mathematical software packages in education. Of course, we do not intend to contest the role of computer packages in engineering education. On the contrary, we are amongst the strong advocates of injecting computer-based exercises into the teaching of mathematics. This new technology is intended to make teaching more effective, to make the mathematics material seem more relevant, to equip students so that they can recognise and cope with situations in engineering where mathematics is appropriate, but we do not expect to succeed in a total substitution of the subject of mathematics by computer packages, however user-friendly and exhaustive they may be. Therefore, from a pedagogical and didactic point of view, the teaching of mathematics must keep pace with new technologies, but in a temperate manner, because computers can not replace the essential metacognitive role of *mathematics learned by pen and paper*. Without an appropriate mathematical knowledge - learned by pencil and paper - our engineering students will tomorrow be poor at employing basic mathematics to link theory and the physical world and will use software packages without an understanding of the fundamental principles on which the software is based. Even though in practice engineers seldom need to apply mathematics at the level taught at a technical university, the study of mathematics must at least be seen as a training in logical thought and creative and inventive skills. These important shaping functions of teaching mathematics can be accomplished only if mathematics is taught in a creative style, in a manner which is appropriate to users and maintains students interest by demonstrating the relevance of mathematics to engineering needs and by emphasising its significance to engineers in developing inventivity, logical analysis and creative thought. If the teaching of mathematics is non-creative, namely if it is reduced to computing without thinking, applying formulae without deducing and reasoning, without reflection on what is being done, then the desired side of the educational process is not attained.

But if the teaching of mathematics is directed toward this creative way, then we can expect at least that our mathematics instruction will help students to think both inside and outside the mathematics subject. Our experiments are however based on a strong argument: in all Romanian schools, beginning with primary schools, continuing with secondary and high schools and finishing with undergraduate and postgraduate courses in universities, mathematics is taught at a very high level. Or, more exactly, it was taught at a high level, because, unfortunately, in the last five years almost all Romanian technical universities have decreased the number of courses in mathematics.

Although, there are many people who argue that a good engineer is not necessarily a good mathematician, we have established a correlation between the high level of mathematics attained at the Romanian technical universities until 1990, on one hand, and the highly appreciated Romanian inventors [14], on the other hand. By means of such examples as the following, we are trying to convince educators in engineering of the metacognitive relevance of mathematics in shaping creative and inventive thought.

Example:
In the course of the year 1994 Romanian inventors obtained [14]: 99 gold medals, 44 silver medals, 23 bronze medals and 15 special prizes, at five international competitions (held in Switzerland, Croatia, U.S.A., Bulgaria and Romania). At the international competition EUREKA (Brussels, 9-16 Nov. 1994), alone the Romanian Institute for Invention obtained no less than 60 medals (40 gold medals, 12 silver medals, 2 bronze medals and 6 special prizes). (Unfortunately, there is not enough money and too little effort is invested in Romania to apply many of these inventions).

In our opinion, students will only become competent Twenty-first Century engineers if they are inventive engineers. So, we think that mathematics - which plays an important role in shaping a creative and inventive thinking - is indeed essential in the engineering curriculum.

2 Basic creative principles for solving a problem

The basic idea of our attempt to develop a creative manner in solving any problems (mathematical, technical and so on) is to try to follow the specific behaviour of a research worker, that is a gradual questioning and answering on the main notions, facts and ideas involved in the problem and its solution. It is far better if we begin to train our engineering students in such a style of work by mathematical problems, because in the early part of their course the students are unfamiliar with the engineering topics. Therefore, this training may be seen as a metacognitive background of their engineering inventive ability, as a preparation of those logical tools which are to be used in their possible future research activity in engineering. In our opinion, in order to equip students with such inventive skills, we must promote a creative behaviour in teaching and learning mathematics.

By creative behaviour we mean, first of all, the style of teaching. Indeed, engineering mathematics could be taught as a vehicle for creative thought and analysis rather that an academic subject which seeks for the most rigorously correct explanation. An active teaching is to be adopted so that the teacher can encourage students in a continuous logical questioning and answering on the facts he teaches and on the reasoning he uses. He will often be willing to reduce the content of courses and to increase the intellectual challenge which he offers. By a creative behaviour in teaching, we further mean a permanent care to equip students with a firm base of mathematical knowledge and a clear understanding of its main concepts together with a constant effort to demonstrate its relevance to engineering needs. Modelling with mathematics is an area where the relevance can be demonstrated most satisfactory, but having in view the fact that students have little or no engineering background at the start of their course, the early examples of modelling should be the simple and realistic.

Following these modelling exercises it is desirable that any engineer should be able to understand the formulation of an engineering problem, to construct a model, to recognise limitations inherent in the model, to follow mathematical arguments in a critical and constructive way and to interpret results from the model in terms of the given engineering problem. In order to train students in a creative learning of mathematics we have to direct the ordinary problem solving session towards an active and creative one. To this end one will follow some general creative principles and suitable strategies in solving problems. These basic principles - as stated in our paper [3] - are the following three ones: 1) the algorithmicity principle; 2) the generality principle; 3) the generalisation principle.

To solve a problem by the applying the *algorithmicity principle* we mean to construct a well ordered solution which includes all essential steps in a gradual succession. The *generality principle* applied in solving a problem assumes to construct or to adopt and to retain only those methods which could be applied to other similar or kindred problems. In short, the generality principle selects the general methods for solving a given (class of) problem(s). By applying the *generalisation principle* in solving a problem, we try to obtain a more general statement of this problem, if possible, the most general statement of it, replacing all particular data or assumption by a general one. It is important to stress the fact that not all mathematical problems can be tackled in such a creative way. Therefore we need a collection of selected problems which can be taken or adapted, by a careful analysis, from several textbooks and collection problems [9]. These exercises and problems can be taken from different levels of mathematical knowledge and can have different degrees of difficulty. By systematically applying one, two or all three of these principles in solving such creative problems, we expect to train students in an active and creative approach to any problem they meet, we hope to discover and develop their inventive abilities and skills inside and outside mathematics courses. To attain this goal we have to choose between initiating special case study exercises inside conventional lectures and problem solving sessions in class on the one hand, and organising special seminars alongside ordinary lectures, on the other hand. Our experiments have been concentrated mainly on combining these two approaches, laying stress on the second. Regarding these special problem solving sessions, we try to solve as many accessible creative problems as possible stressing the clear application of each creative principle, in order to help students to learn to:

- analyse carefully the statement of the problem,
- construct logically an algorithmic solution,
- analyse in detail the critical steps and reasonings in the obtained solution,
- discover the reasonings we can improve or generalise,
- detect and replace any particular data and assumptions by a general one,
- endow with generality attributes the method(s), algorithms and techniques used,
- discover as many questions arising from the given problem and its solution as possible,
- answer these questions in a critical way and to formulate new problems arising from the given problem,
- summarise and report conclusions.

After five years of experience and in view of our partial evaluation we are convinced that, if we solve together a sufficient number of such problems and then the students solve themselves other similar or kindred problems, we discover, form and develop a creative manner and reasoning in our students. We think this methodology can be easily adopted and adapted in teaching other fundamental, technical or non-technical subjection the engineering curriculum.

3 Case studies

A collection of case studies is being prepared by the author and it is hoped that it will soon be published. It would be desirable that the book should be accompanied by a software library suitable for computer aided lessons, as in [5] and [2]. From a didactic point of view, in solving these problems we will simultaneously stress the main steps in modelling a physical problem, because a mathematics course specially for engineers must clearly show students that the application of mathematics to an engineering problem consists essentially in the following three phases:

- translation of the given physical information into a mathematical form, that is a construction of a mathematical model of the physical situation;
- treatment of the model by mathematical methods and solving of the obtained equations by analytical or numerical methods. This furnishes the solution of the given problem in mathematical form;
- interpretation of the mathematical results in the physical terms.

All three steps seem to be of equal importance in modelling, but it is generally very difficult to interest students in solving such problems. As it can be seen [2], [8], our creative approach is rather convenient for illustrating these modelling phases too and to encourage students to practise it.

Each principle has its own relevance, the most important seems to be the *generalisation principle* which allowed us to initiate explorations in many directions [4], [8]. If we succeed in emphasising so many aspects starting from a given problem, we form and train a creative manner of thinking and reasoning, we develop inventive skills in our students. But, how many problems can we solve in such a creative manner during the mathematical instruction of our students?

To be honest: very few. However, we could use parts of this creative style of teaching (or we simply use it, consciously or not) in our activity, instead of the whole approach which is very difficult to implement. In any case, I am convinced that success in training such creative skills and abilities depends in a large measure on the existence of such creative moments in our teaching activity.

I occasionally inserted them in my lectures and frequently in problem solving session class. A correlation between this style of teaching and the inventive abilities in which we train our students, has been studied on a sample of graduates (three engineering programs) and reported elsewhere (see section 4). After these experiments we are convinced that, if we solve together a sufficient number of such problems and then the students solve by themselves other similar or kindred problems, we contribute to the development of their metacognitive inventive skills. but it is important to stress the fact that not any problem or exercise can be tackled in such a creative way. During the last ten years, I have made a collection in a special problem solving session - The Seminar on Creative Mathematics - intend to stimulate the research abilities of the students from the mathematics and some engineering programs at our University.

This activity usually covers 6 weeks, but we are going to extend it to 12 weeks. Any weekly session consists in

- a problem solving session in class,
- home work,
- reports on the individual (or team) activity.

4 Evaluation and final conclusions

Following a certain measure the creative style described in section 2 and 3 we have taught a course of lectures to the mechanical engineering programme and to the electromechanical engineering programme. We have also taught two courses of lectures to the metallurgy programme following in a large measure the principles described. Inventive abilities and skills have been evaluated by the activity of the Seminar on Engineering Invention (directed by Professor Gh.Volcovinschi). His report is the following [6]:

- Metallurgy programme (1990 - 1995): from 28 graduates we have 6 promising inventors;
- Electromechanical
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References

[1] Barry,M.D.I. and
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[2] Berinde,V. (1995)
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industry", 18-20 S
pp.19-29

[3] Berinde,V. (1994)
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[4] Berinde,V. (1994)
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[5] Berinde,V. and O.
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[6] Berinde,V. and Gh
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[7] Berinde,V. (1995)
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[8] Berinde,V. (1995)
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[9] Clayton,B.R. (199
Mustoe, L.R. and
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[10] Craggs,I.W. (197
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[11] Grandsard,F. (198
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[12] Grandsard,F. (199
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- Electromechanical programme (1990 - 1995): from 25 graduates we have 1 promising inventor;
- Mechanical engineering programme (1990 - 1995): from 50 graduates we have 2 promising inventors.

In spite of our particular experiments - on a sample of metallurgy, electromechanical and mechanical engineering, from a single series of graduates - the results obtained encourage us to extend and to recommend this creative teaching and learning to other basic subjects in the engineering curriculum and to other programs. Furthermore, a clear correlation between the mathematical knowledge of the students and aptitude in invention (eight of nine promising inventors obtained high marks at all mathematical examinations) it is shown by our experiments.

References

[1] Barry,M.D.I. and N.C.Steele (1992) A core curriculum in mathematics for the European engineer, Document 92.1 SEFI Bruxelles

[2] Berinde,V. (1995) How to stimulate engineering invention by means of mathematical approaches, Proceed.Int.Conference "Teaching Mathematics for industry", 18-20 Sept.1994 (Ed. J.Cerny), CTU Publishing House, Prague, pp.19-29

[3] Berinde,V. (1994) Basic principles concerning the creative solution of problems (in Romanian), *Lucr.Sem.Creativ.Mat.,* vol. 3 (1993-1994), 89-98

[4] Berinde,V. (1994) Strategies for solving "following problems" (in Romanian), *Lucr.Sem.Creativ.Mat.*, vol. 3 (1993-1994), 29-42

[5] Berinde,V. and O.Cosma (1994) An elementary geometric construction performed by a computer, *Bul.St.Univ.Baia Mare*, vol.X, 99-108

[6] Berinde,V. and Gh.Volcovinschi (1995) About the relevance of developing the creative and inventive abilities to engineering students by means of nontechnical courses, Inter.Conf. "Educating the whole engineer", Cracow Univ. of Technology, 4-6 May 1995, to appear in SEFI Document No. 15, 1995

[7] Berinde,V. (1995) Active problem based learning for developing the inventive abilities of engineering students, Proceedings of SEFI/CDWG Conference 1995, 1-3 November 1995, Univ. of Twente, The Netherlands (to appear)

[8] Berinde,V. (1995) A collection of creatively solved problems for simulating the inventive abilities of students, ICTMT, Napier University Edinburgh, 4-7 September 1995

[9] Clayton,B.R. (1995) Mathematics for engineers: an integrated approach in Mustoe, L.R. and S.Hibberd (eds) Proceed. of Conf."Mathematical education of engineers", Oxford University Press

[10] Craggs,I.W. (1978) Rigorous engineering mathematics, *Bull.I.M.A.*, 1979, pp.307-308

[11] Grandsard,F. (1989) Problem solving for first year university students, in Modelling, Applications and Applied Problem - Solving, Blum,W., Niss,M. and Huntley,I.(eds), Ellis Horwood

[12] Grandsard,F. (1990) Can a local problem solving contest help to develop problem solving skills?, *Mathematics Competitions*, Vol. 3, No 1, 53-56

[13] Mustoe,L. (1994) Industry experts - but who should determine the curriculum?, SEFI Math. Working Group Newsletter, Nov.1994, 2-25

[14] Plahteanu,B. (1995) 1994 - A new horizon of the Romanian invention (in Romanian), National Institute for Invention, Iasi, Romania

[15] Polya,G. (1965) Mathematical discovery. On understanding, learning and teaching problem solving, John Wiley & Sons, New York

[16] Pope, I.A. (1978) The mathematical education of engineers - where next?, *Bull.I.M.A.*, 274-278

[17] Rade,L. (editor) (1993) Teaching of Modern Engineering Mathematics, Studentliteratur & Chartwell - Bratt, Lund, Sweden

[18] Shercliff,I.A. (1978) Can mathematics form the heart of the engineering curriculum?, *Bull.I.M.A.*, 279-281

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D.M. DIMOV
Department of Str
Bulgaria

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1 Introduction

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