The Design and Application of Interactive Computer Programs for Teaching of Engineering Theory and Design

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Abstract

The paper describes the development, content and evaluation of a multimedia program for the teaching and for the conduct of tutorials. The subject is theory and design of reinforced concrete columns. It is postulated that the program organisation could be used to advantage in the teaching of most applied science subjects.

Keywords

science teaching, multimedia teaching, computer programs, civil engineering, concrete

1. Introduction

1.1 The educational context

The teaching of the applied sciences has been the subject of an ongoing debate since the time of Galileo. At the time, it will be recalled, the sciences were considered to be subservient to theological dogma. During the Renaissance this particular view gradually fell from favour. However, in continental Europe, applied sciences were not considered to be suitable subjects for teaching at universities, the argument being that they were derivatives from pure science and philosophy, and did not lend themselves to teaching methods employed in the humanities.

This resulted in two different developments:

In continental Europe, the applied sciences were taught in special tertiary schools, variously called Technische Hochschule (Technical Higher Schools), Ecoles Polytechniques, Polytecnico, and Institutes of Technology. These establishments should not be confused with our former Technical Colleges, as the former offer engineering courses of, generally, 10-12 semesters, against the Technical College Diploma courses of six semesters. Some of the European establishments, although not all, have adopted the title of University of Technology.

In the United Kingdom, originally, one became an engineer by following an “apprenticeship” under an experienced engineer, and then sitting an entrance examination to one of the learned institutions. Engineering is now taught at universities as a science course. After suitable experience one is required to do an oral presentation to an examination panel in order to gain access to membership of the relevant institution.

In Australia, engineering education has been established through the faculties of engineering of the various universities as a four-year degree course. In addition there was a system of Technical Colleges providing a three-year diploma course. Both the degree and the diploma courses gave access to Membership of the Institution of Engineers after suitable periods of practical experience. When the Institution gave notice of its intention to recognise only four-year engineering courses as from 1984, the Technical Colleges began to offer four-year degree courses, and subsequently, under the present government policy became Universities of Technology.

The above preamble alludes to the fact that in engineering education one can discern two distinct approaches:

- the approach which seeks to teach engineering by starting from the precepts of pure science and formulating design and construction rules which will lead to engineering constructions which suit their stated purpose,

- the approach which teaches engineering by familiarising the students with the basic laws of mechanics and with the design rules, however, without accentuating the foundation of these rules. With the aid of the laws of mechanics the would-be engineer can compute the actions to which the engineering construction is subjected, while knowledge of the design rules enables him / her to choose the appropriate materials and dimensions.

In the former case, the engineer becomes aware of why the rules are as they are; in the latter, he / she learns to apply the rules. More importantly, in the former case the engineer becomes aware of areas where science has (as yet) failed to provide a satisfactory explication of the behaviour of the construction, and where recourse must be had to empirical rules. This awareness is the driving force behind much of the engineering research being done at universities.

From an educational viewpoint, there can be little doubt that both approaches regarding what needs to be learned require small classes with ample opportunity for interaction between lecturers and students. The Socratic mode of teaching, by discussion, questions and answers, is ideal for the teaching of engineering theory. Similarly, for practice classes or tutorials it is not only necessary, but imperative, to limit class sizes to no more than 20 students per tutor. Experience with this sort of arrangement shows that no more than two tutors should operate in the same room, limiting the number of students per class to 40. As an alternative, additional tutorial rooms may be provided, but this quickly leads to logistic problems.

Within this context, the relationship between theory and practice continues to be one of the most vexed issues of professional education in the applied sciences in general and in engineering in particular. Academic teachers struggle to ‘get through’ the mass of theoretical concepts which underlie their discipline, while students complain of lack of ‘relevance’ to their future profession. At the heart of this conflict is a fundamental difference between the teaching of engineering theory and practice and the students’ approach to learning and the acquisition of knowledge.

1.2 The engineering context

The last paragraph of the previous section deserves further consideration: from discussions with engineering students, from their comments on course material, and finally, comparing methods of delivery in different countries, it is obvious that engineering students find difficulty in learning engineering theory without the benefit of its application in practice.

It must be said here that the various branches of engineering theory contain concepts which are not always easy to grasp. Equally, the practical significance of these concepts is often obscure, and is only demonstrated much later, if at all. In view of the dichotomy between the learning of theory and of its application, it would seem important that the following two precepts be adhered to as much as circumstances will allow:

- in the teaching of engineering theory the practical relevance of the subject matter should be stressed at frequent intervals,
- teaching of any theoretical concept should be followed as soon as practicable by a tutorial exercise showing the practical application of that concept. Ideally, these exercises should set a problem which the student can perceive as practical, i.e., a problem he / she might have to solve "in real life".

Figure 1, below, graphically shows the learning preference of engineering students noted above.

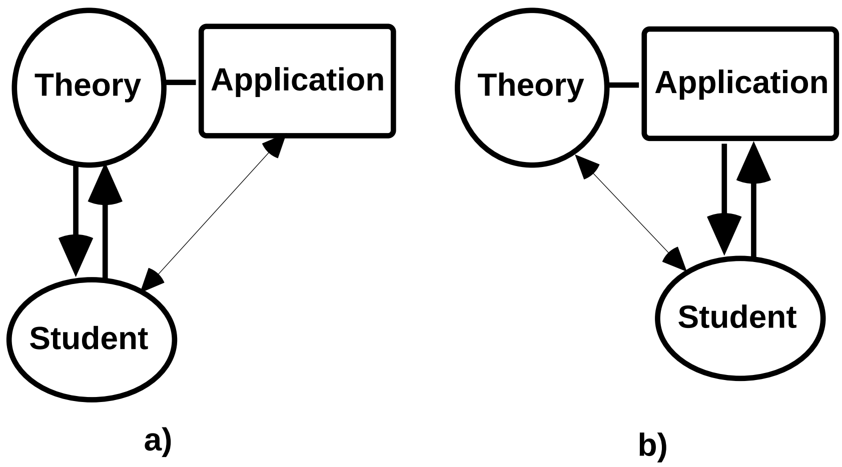

Figure 1 - Knowledge acquisition by a) a typical science student, and b) an engineering student

An immediate practical problem which arises when one attempts to implement a teaching mode which interleaves theory and practice is the inordinately long time required to perform the relevant practical computations by hand. The introduction of the electronic calculator has alleviated this problem somewhat, but has by no means eradicated it. Generally, in the Department of Civil and Environmental Engineering, The University of Melbourne, it is considered that there should be one practice class in every three contact hours. This is at best a compromise for the following reasons:

- psychologically it is very important that the students be able to complete the practice class assignment within the allocated hour. However, as one advances in the engineering course, it becomes increasingly difficult to set a realistic practical exercise which can be completed in that time span with the computational tools available.
- if one extends the time available for the solution of a practical problem, one encroaches on the time available for the teaching of theory, with the result that this teaching starts to suffer from being rushed, with all the consequences of lack of understanding, etc.

This paper reports on an attempted solution to the above problems by the introduction of a multimedia teaching program in which the presentation of the theory is interwoven with an application package.

1.3 The University environment

The program “Maestro”, dealing with the teaching of theory and practice of the design of reinforced concrete columns, was developed by the first author after his having attended a continuing education course on “Spreadsheets in Concrete Design” presented by the second author. The two authors have been collaborating since that time, the aim being to create a suite of programs which will cover the entire under-graduate course in reinforced concrete. Columns were chosen as a prototype development, as the authors judged that if this topic could be successfully tackled, the whole course could.

The program consists of two main sections, the theory and the application part. The former makes use of animated graphics to explain the theory, the latter makes extensive use of a spreadsheet format to enable computations to be performed fast and with clarity. In addition, the latter format enables the student to perform “what, if?” analyses, a feature not previously available in manual tutorials.

The program is designed around the availability within the university of a number of “high-tech” lecture theatres which allow the presentation of multimedia software through computers controlled by the lecturer from the front of the class, and projected by colour video projectors onto the front wall of the theatre. This arrangement allows the program to be presented in its teaching mode.

In addition, the program is mounted on the file server of one of the computer laboratories, where students use it to solve the tutorial problems. This represents the program in its tutorial mode.

2. Program Development

2.1 Engineering content

Reinforced concrete columns consist of a usually rectangular or round concrete cross-sectional shape with longitudinal reinforcing bars embedded in the concrete. These bars are embedded a certain distance (cover) from the surface. Columns are subjected to a bending action (the so-called bending moment), and a thrust, the direct force. They have to be designed to withstand this load combination. These fundamentals are shown in figure 2, below, a screen dump from the actual program, reproduced here in black-and-white.

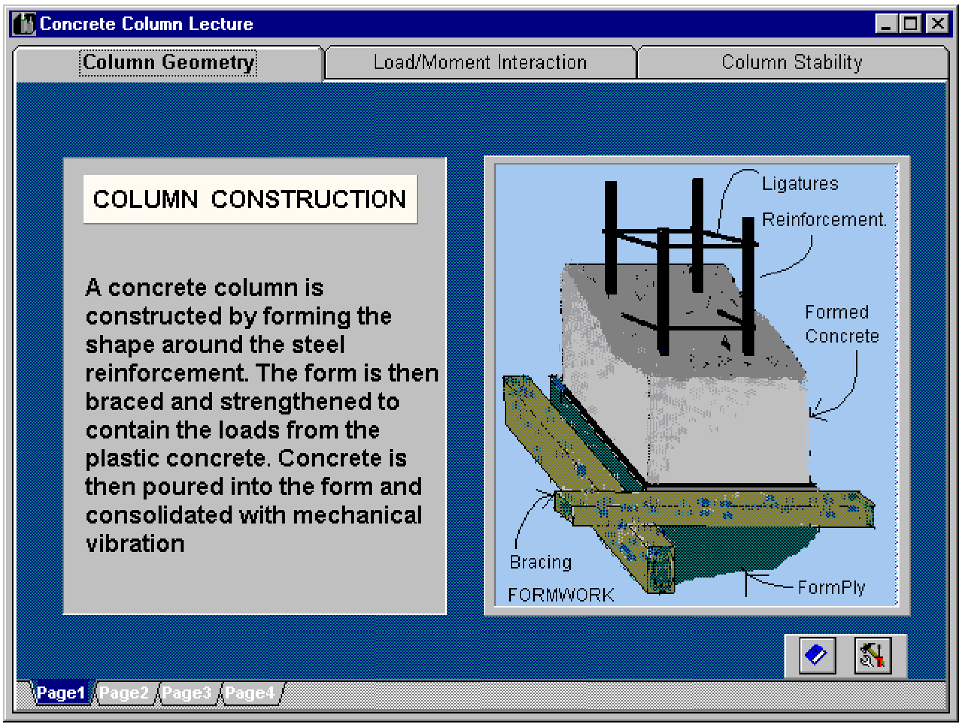

Figure 2 - Program introduction

Of necessity, the "design" of reinforced concrete columns is an iterative procedure: one chooses a column size and its reinforcement, and determines the ultimate load combination which it will withstand. One then compares this with the ultimate load to which it will be subjected. Finally, the column size and / or the reinforcement are adjusted as indicated by the comparison, and the procedure is repeated until a safe and economical solution is found.

First, the program deals with the properties of the concrete and reinforcing steel separately, and when combined in a column configuration. The latter are the geometrical properties used in the design. Secondly, the program determines the array of load combinations which a column with these properties will be able to withstand, producing a graphical representation of the combinations of ultimate direct force and bending moment, the interaction diagram.

Thirdly, the program examines the effects of the design ultimate load combination and the column length, noting that the behaviour of columns under load varies with their lengths. Short, stocky columns will fail by crushing of the concrete, while long, slender ones might buckle under only a small fraction of the crushing load.

Finally, a graphical representation of the column behaviour under the design load combination, the loading line, is superimposed on the interaction diagram, the intersection of the two yielding the column capacity for that load combination. This is shown in figure 3, below:

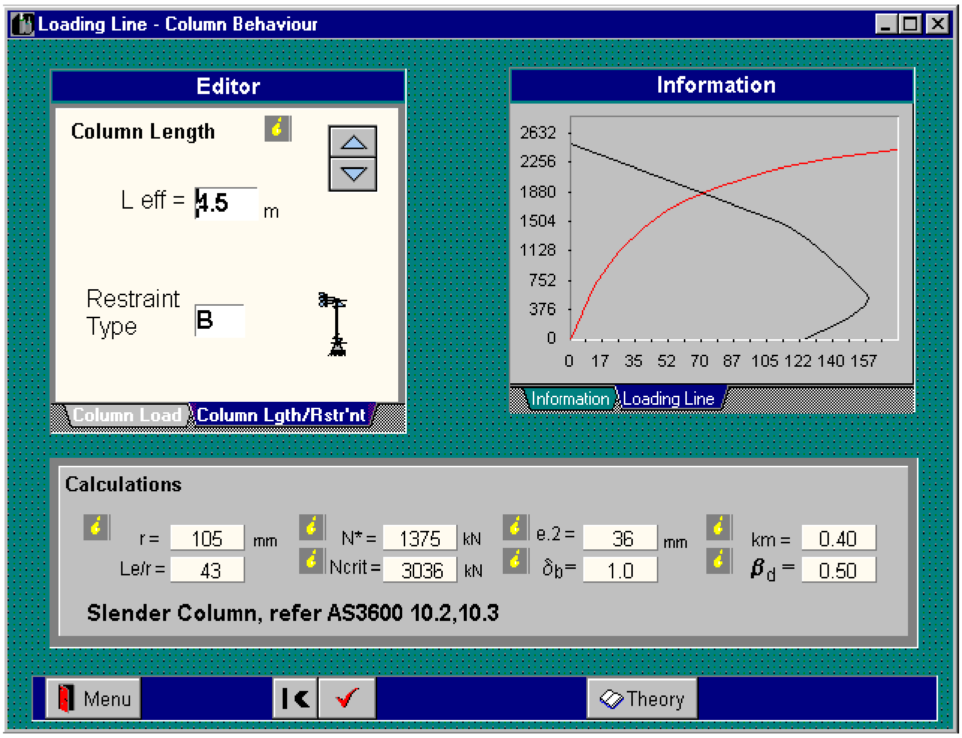

Figure 3 - Graphical representation of inter-action diagram and loading line.

2.2 Program format

The program deals with each of the above three areas by using an interactive application program which runs parallel with a theoretical presentation. The theoretical and practical sessions are aware of each other, thus switching between the theoretical content and the interactive example is always relevant to the topic in hand. For example, switching from the theoretical presentation of column behaviour to the interactive example will take the user directly to the behaviour area of the interactive example and vice-versa. The interactive example remains consistent throughout the program, the parameters set in the initial segment being carried throughout the entire application. However, the user is not bound to initial settings. The program features sophisticated methods to carry forward or backtrack, review or modify parameters, enabling a "what, if....?" scenario to be run either during the lecture, or as a practical problem during a tutorial.

2.3 Program design

Designing a teaching program requires exclusive features which render the program easy to use. This is particularly important for complex subjects such as the reinforced concrete columns covered here. The program must have a transparent user interface, that is, the user must not be burdened by having to learn how to use the program. The program must be self-explanatory. This is achieved by having a simple, consistent user interface. There are few controls but each control carries an explanatory graphic icon and an automatic small balloon help message, telling the user of its specific function. The two distinct program areas can be categorised as theory and interactive example. Symbols and colours play an important role in defining the program areas and simple analogy is used to distinguish them. An open book graphic is used to symbolise the reference to the text book for theoretical information, whereas a cluster of construction tools is used to symbolise the practical area of the program. The user presses buttons to access each area. Colour is used to signify the program location, a combination of different colours and textures are used in each program area, consequently the user always knows his location inside the program simply by its colour and "feel".

2.4 Use as tutorial program

Relevance is of great importance to the applied sciences. Tutorials have long been the doorway to practical relevance in engineering instruction, where masses of theory are inevitably put to use. These tutorials have also been the bane of many students who have difficulty interrelating new and only partly assimilated theoretical concepts to the solution of practical problems. Limited time and resources are usually wasted before a procedure or some sort of protocol is established. The program addresses this issue within the interactive example content. A procedure is already established within the program user interface, and the user does not spend time establishing a protocol but immediately begins the task of tackling a real problem in conjunction with the theoretical considerations.

2.5 Relevance to design codes

Construction standards and design rules are accessible to the user. These scan the example proposed by the user and flag any violations of design and construction regulations, or of practical considerations such as congestion of reinforcing steel, thus exposing the user to a true practical experience.

3. Results of prototype trial

3.1 Trial environment

The program's first version was used as a trial in the first semester, 1995, in the actual 4th year lectures on reinforced concrete theory and design, subject 421-410. The lectures in this subject conventionally cover four lectures and two tutorials on reinforced concrete columns. The class size was 41.

The lectures were held in the Department's A1 lecture theatre, which is equipped with the necessary electronic and computer equipment to present the program. The tutorial sessions were held in the faculty computer laboratories, where the program was installed on the file server.

The version 1.0 required loading of three 3.5 inch diskettes, which has now been reduced to one diskette, thus simplifying loading the program, and making it faster in its operation. The trials made it obvious that this needed to be done.

Apart from some minor problems with loading the program from the file server to the individual computers, the whole trial was executed without a hitch. From a productivity point of view, one hour of lectures was saved, the two tutorials were supervised by one lecturer without the help of any tutors, and all students completed their tutorial tasks substantially within the hour set aside for the purpose. Some students did some extra work on the subject in their own time.

At the end of the programme a questionnaire was completed by the students, the results of which will be reported in section 3.2. Also, the subject matter could be identified in the examination held at the end of the first semester, while similar results were available for the year 1994. An analysis of these results is given in section 3.3.

3.2 Questionnaire

The questionnaire used to evaluate the effectiveness of the program is attached as Appendix A. 33 students out of a possible 41 completed it. In Appendix A the figures behind each question are the weighted average of the replies received for that question, standardised to a mark out of 10, thus producing an "approval rating".

It will be seen that the mean approval rating of the program as a teaching tool is 7.9, using an equal weighting for each question. As the program was not designed to “increase the depth of (your) understanding of the subject”, downgrading the result of that question would be justified, increasing the approval rating to 8.2.

Similarly, the mean approval rating of the program as a tutorial tool was 8.9.

As a matter of interest, the answers were segregated by sex, and it was found that the female students’ approval rating was somewhat higher than that of the males. Favourable or encouraging comments in the appropriate spaces of the questionnaire outweighed negative ones in a ratio of 5:1.

Criticisms voiced in the appropriate parts of the questionnaire were concerned with the rather long response times of the program, and with a repetitive, rather tedious operation which had to be performed as part of the application process. Both these points have been addressed in later versions.

3.3 Relevant exam results

Of the mid-year examination in the subject, two questions were directly related to the topic of reinforced concrete column design. Their value was 25 marks out of 90, or 28% of the total concrete examination. Table 1, below, shows a statistical analysis of the results of the 1995 examination, together with a similar analysis of the same examination held in 1994.

Year	**Concrete Examination**		**Concrete Column Questions**		**Col./Total**
	Mean %	**Std Dev. %**	**Mean %**	**Std Dev. %**	**Col. (4)/Col. (2)**
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
1994	58.6	18.2	54.3	22.0	0.92
1995	68.0	12.0	69.8	25.0	1.02

Table 1. Comparison of Examination Results.

These results show that, while in 1994 the concrete column results were below the examination mean by 8%, in 1995 they were above the examination mean by 2%, which seems to indicate an improvement of the students’ understanding of the subject, notwithstanding their not being aware of it (viz. Q. 1c of the questionnaire). It should be noted that historically, the concrete column questions scored below the average for the whole examination, indicating the difficulty of mastering this topic. This problem appears to have been remedied by the use of the computer program.

A matter for concern is the relatively high standard deviation of the results. Improvement in teaching using the program might remedy this. Teaching procedures using interactive computer programs materially differs from conventional methods, and the lecturer has to develop new skills in order to realise its potential advantages.

APPENDIX A

UNIVERSITY OF MELBOURNE

DEPARTMENT OF CIVIL AND AGRICULTURAL ENGINEERING

CONCRETE THEORY AND DESIGN, 421-410, 1995

Questionnaire, Use of Touch learning / tutorial computer program

Please give the following questions a rating 1-5 (strongly disagree - strongly agree, respectively).

A. Learning

1a. Do you think that the use of the Touch computer program enhanced your ability to learn	8.0
b. Did it increase your speed of comprehension	8.0
c. Did it increase the depth of your understanding of the subject	6.9
d. Did the style of lecturing suit the use of the program	8.5

Remarks on Learning:

(e.g. comments on screen lay-out, operation of cursor, etc.)

B. Tutorial

2a. Did you find that using the program as a tutorial tool enhanced your understanding of the subject	8.5
b. Do you think that using the program as a tutorial tool is more efficient than the normal manual tutorial exercise	8.8
c. Were the two tutorial problems set appropriate to the use of the program	9.5

Remarks on Tutorials:

Suggestions for improvement: