The Changing Relationship: Civil/Structural Engineers and Maths

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Published in *The Structural Engineer – 2nd April 2002*

Synopsis

Mathematics is vital for civil engineers but its role is changing. Arup chairman Duncan Michael [1] has argued for less emphasis on the teaching of mathematics. Here we report on a necessary change of emphasis but also argue the importance of a good mathematical education for all engineers.

Introduction

We presume that when Duncan Michael justifies his statement that we should teach far less mathematics to our young engineers by saying that 'anyone over 50 today is unlikely to be able to break out sufficiently from their acquired beliefs and presumptions' he includes himself! In our experience, this ability to adapt and change is less to do with actual age than with attitude. We have met young people who are old in this respect and old people that are young! Certainly, those in University research and education must keep young! As the first author has recently written a text Doing it Differently [2] we feel in a good position to discuss Duncan Michael's case even though we are both over 50!

His assertions are nothing new. When three mathematicians were asked in 1742-3 by Pope Benedict XIV to examine the cracked dome of St Peter's their report was severely criticised at the time. 'If it was possible to design and build St. Peter's dome without mathematics and especially without the new fangled mechanics of our time, it will also be possible to restore it without the aid of mathematicians …… Michaelangelo knew no mathematics and yet was able to build the dome' [3]. There have been innumerable statements by people rejecting the need for mathematics but time and time again history has shown them to be wrong. What is esoteric and complex in one era may become commonplace in the next.

However, there is a major difference in modern times and that is the power of modern computers and this has a serious effect in the way we think and use mathematics. No longer do we have to 'plough through' long pages of deductive proof – the computer will do it for us. No longer do we have grind through long calculations – the computer will do it for us. The challenge has changed from the ability to do this to the ability to interpret the meaning of mathematics to engineering and herein lies the challenge and change of emphasis.

Did you Learn Tables at School?

When electronic calculators were first available the teaching of tables was abandoned by many schools. At that time the first author came across a 15 year old who knew what multiplication was but not what the answer to 12x5 was without a calculator. However she knew to write 5 down 12 times and add them up! Fortunately many schools now teach tables as well as the use of calculators.

Those of us over 50 were generally taught mathematics purely on the basis of it being a tool for calculation.

Mathematics is a Language of Scientific Communication

If you were dropped off somewhere remote in France and told to find your way to somewhere else rather remote you will certainly find it easier if you speak French. Of course you may probably succeed without being able to speak French at all but it may take you longer or you may encounter other difficulties. The same is true of mathematics because it is the language of scientific communication. Without a facility in mathematics you cut engineers off from scientific change and development. Engineers so often confuse the science with the language and what is being rejected is not mathematics per se but inappropriate theory. There is a place for all levels of theory.

The understanding of a physical phenomena such as structural behaviour is very important – but that is no reason to reject mathematics. Many of us learned how stiffness attracts moment through many many moment distribution calculations. This however is not sufficient to justify teaching moment distribution when it is so much easier to use a PC. However how do young people learn about stiffness and moment? – that is the challenge to modern teachers of structural analysis. All of those matters learned by grinding through lots and lots of examples have now to be learned more efficiently – but how? One thing is clear: if an engineer is 'blinded' by an inability to understand the language of a book or technical article then important engineering phenomena may well be misunderstood or missed completely.

Mathematics is About Rigour

Many of us over 50 enjoyed Euclidean geometry and the beauty of theorem proving. This is no longer in the syllabus. However all mathematics is the ultimate form of logical rigour. This is certainly a quality required of engineers. The over concentration on getting the 'right answer' in a mathematical question at school has been to smother creative thinking in many people but one must be careful not to throw the baby out with the bathwater. In these modern times when people are increasingly relying on 'bullet point' presentations the ability to work through a set of ideas using a strongly logical mind is of very great importance. We also find that the preparation of engineers in Europe is to a level of mathematics that our students find it hard to compete with – we must be able to compete with the best in the world.

Mathematics Is a Dense Language

We learn mathematics sequentially and we gradually build layers of understanding. You cannot dip in and out of mathematics. This makes it inhibiting to many because unless you have understood the lower layers you cannot hope to understand the higher ones. Thus many become frightened of mathematics. The language is dense and hard – but is essentially why it is educationally important to train the minds of our young people. We need engineers who are at ease with it and who can take advantage of new ideas and use them appropriately even if they are expressed using advanced mathematics. Technician engineers will need less mathematics than chartered engineers but both need to be comfortable with an appropriate level of skills for the responsibilities they take on.

Computation has Over Taken the Calculation and Deduction

Thus the new emphasis is on modelling. If we have a problem – a structure to design – then modelling is about 1) building an appropriate theoretical model, 2) deducing some results from it and 3) interpreting those results into decisions regarding your structure. The model may be a physical model, say of cardboard, to examine how the structure may be assembled. The model may be a theoretical model based on physics but expressed using mathematics. Traditionally almost all of the focus of engineering education has been on the middle step that involves mathematical manipulations. Now it is on steps one and three. In that modelling our scientific understanding of physical (and human systems) is crucial. Intuition can be wrong – science is about making our models objective (i.e. describing things in a way that can be shared by others [4]), testing those models and updating them. We get dependable information when we can measure it (necessarily involving mathematics) and when we can subject it to intense scrutiny from all angles.

Examples of Pitfalls

We will now quote just two examples of where inadequate understanding of science and mathematics can lead us astray.

Finite element approximations

Our colleagues have experienced many examples of practising engineers making wrong assumptions in finite element modelling. It is very easy to get the right answer to the wrong problem. All packages have limitations and we have experienced examples where engineers have set, as boundary conditions, degrees of freedom that were not present. Many engineers seem not to realise that using grillages to model a slab will not adequately model torsion. A Chartered engineer must have a strong understanding of the analysis packages used and this requires an adequate level of mathematical knowledge.

Reliability Theory

Few practising engineers have a good grounding in probability theory. In the minds of most engineers probability theory is synonymous with statistics. They know their business is one where data is sparse. Hence statistics and probability theory are dismissed by the vast majority of engineers as being of little interest. Over many years mathematically inclined engineers have developed reliability theory based on the use of probability theory. Where data is sparse they use the so-called Bayesian approach that uses subjective judgement in a very special but rigorous way. Few engineers are able to criticise the approach adequately because of their inadequate understanding of probability theory. Thus the problem of incompleteness in reliability calculations written about extensively by the first author are not appreciated. This is very dangerous since risk numbers are used by some engineers that are totally spurious. Here is an example where modern mathematics should be taught to engineering undergraduates so that they have the theoretical understanding to address one of the most basic issues in modern society – the way we handle risk.

We Believe we Need a Systems Approach

In his recent presidential address to the Institution of Structural Engineers [4] the first author has argued for a systems approach to engineering. This is the real paradigm shift that we think Duncan Michael should focus on. In our research using mathematics we have produced several new approaches including two new theories from using this thinking – structural vulnerability theory and the Interacting Objects Process Model [5,6]. Rather than deprecating the use of mathematics which will reduce our capacity to develop new ideas we should be looking for new ways of using it where it is appropriate and teaching our young engineers to understand and to use the language of mathematics in their qualitative and quantitative work.

References

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