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Towards an Improved Teaching of Structural Behaviour

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Towards an Improved Teaching of Structural Behaviour

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Abstract

The interpretation of mathematical models and how they relate to the physical world is a key skill of the practice of structural engineering. At undergraduate level, there has been a noted reduction in students' physical intuition in recent years. The teaching of structural engineering must therefore adapt itself to these new realities to maintain public confidence in the safety of society's infrastructure.

The work carried out for this Fellowship project tackled the identified deficits at two ends of the spectrum of physical intuition. Third year students were introduced to basic structural models, whilst final year students were exposed to the inner workings of structural engineering software so that they may better link their hand calculations and typical commercial software. Pre- and post-testing using multiple choice questions were used to ascertain the effectiveness of the interventions. The results are generally inconclusive as evidence was found that the multiple choice questions may not be the best form of assessing interventions in physical reasoning. It is clear that more work remains to be done in this area.

Keywords: structural engineering, structural behaviour, physical intuition, multiple choice questions

Introduction

Structural engineering brings mathematics and physics together to solve real-world problems, such as the design of bridges and buildings. A core competency of its practitioners is therefore an ability to physically interpret abstract mathematical models. Failures to do so have serious consequences for public safety.

In the teaching of structural engineering (course DT024), there is an increasing disconnect noted between the mathematical models used, and the physical interpretation of results. This could be arising from reduced tactile experience in childhood: for example, a recent class survey found only about 4% of students had ever built a tree-house. Ironically, this is happening as computer modelling has become standard in the practice of structural engineering. This is exacerbating the problem, as improper understanding of the physical implications of the models used in computer software can lead to structural failures (and already has). It therefore falls to teachers of structural engineering to expose students to more physical experimentation than has been traditionally included in courses.

It should be noted that this problem is not unique to DIT, but is extensively documented for UK institutions in particular. The Institution of Structural Engineers has introduced an annual academic conference to address this problem, and many papers and reports have been prepared (see Further Reading section).

Outline of the Project

This work aims to improve students' physical interpretation of mathematical models through model-building, physical testing, and computer modelling. Such an improvement will cut across all course modules, and should reveal itself in improved student engagement with the subject-matter, with consequent improved outcomes.

Interventions

There is a spectrum of physical intuition that runs from a very basic ability to predict the physical outcome of very basic actions (such as, "if I stand on this plank it will bend"), to the interpretation of numerical models and what their answer means in the physical world (such as, "a negative value for the support reaction does not make sense here as the plank is not trying to lift"). This work intervenes at both ends of this spectrum.
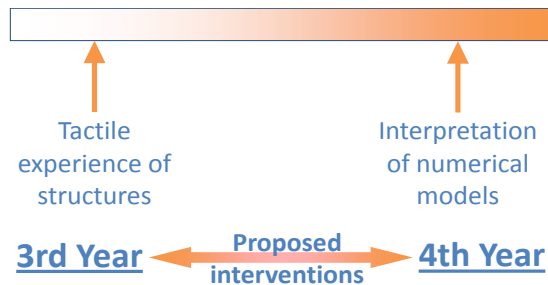

Figure 3.1: Spectrum of intuition and interventions

Third Year Intervention (DT024/3)

Third year students of structural engineering were sequentially exposed to physical model building, basic computer modelling, and interpretation of basic mathematical results. In this order, it was hoped that the student would link from the physical behaviour of structures, towards the mathematical modelling thereof. Figure 3.2 shows how the abstract classroom models were brought to the physical world and investigated by the students. The work programme culminated with a group project combining all three aspects, with associated presentation, calculation, and physical testing: the Spaghetti Bridge Competition.

Figure 3.2: Early-stage building of physical intuition of structural behaviour

Fourth Year Intervention (DT024/4)

Fourth year students were introduced to bespoke educational software (*TrussMaster* – see www.colincaprani.com) that exposes the "black box" calculation steps of standard engineering analysis programs in a way that links directly to the traditional lecture material and basic calculations carried out in class (Figure 3.3). Having linked the class material and software calculations together, the students examined a range of sample problems using the software, some of which are physically unreasonable, and also carried out hand calculations on same. Through exposure to both "good" structural modelling and selected sample "bad" structural modelling, it was hoped that the students would link from numerical modelling towards physical intuition.
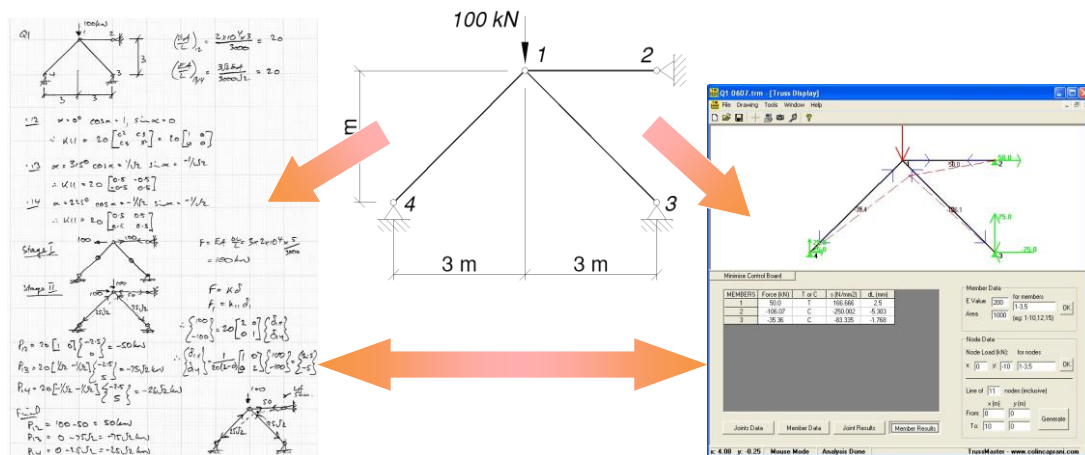
Figure 3.3: Late-stage interpretation of numerical models

Assessment of Interventions

The effectiveness of the two approaches outlined was measured using pre- and post-testing. A novel feature of this work (at least in structural engineering education) was the use of multiple-choice questions (MCQs) for the testing. The project effectiveness will also be measured qualitatively through student focus-groups.

For each intervention, 15 MCQs were to be answered in 15 minutes. Each question had three options, and the very same test was used for both pre- and post-testing. This was possible as the students were not allowed keep the question sheet. A standard gain analysis was then implemented for each student:

- Let P1 = pre-test score;
- P2 = post-test score;
- Scope = 100 - P1 (i.e. the scope for the student to improve);
- Gain = P2 - P1 (the actual gain in score);
- Improvement = Gain/Scope (a percentage measure of improvement).

Results and Analysis

Histograms of marks, gain (i.e. change in marks), and improvement are shown in Figures 3.4 and 3.5. From these figures it can be seen that for both classes there was an appreciable gain in marks and improvement in knowledge. This is certainly to be expected. However, there are several important features of these results that require further explanation:

1. Figure 3.4(a) shows that the pre-test marks for both interventions were too high. It is typically expected that before a concept is taught, a pre-test mark should score quite low, perhaps around 20-30%. In the cases here, the average marks are about 60–70%. This means that the tests were not a stringent enough assessment of conceptual understanding.
2. Figure 3.5 shows that there is an improvement averaging around 40% for both groups. However, several students show negative improvement and scored less in the post-test than in the pre-test. In one case, a student showed a complete negative improvement (i.e., the student got no questions correct both times).
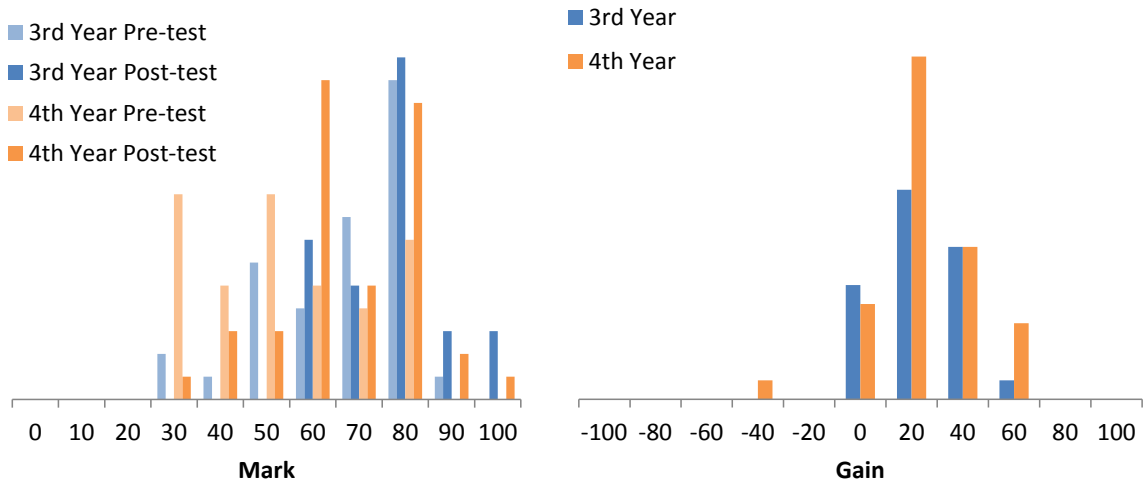
(a) Pre- and post-test marks;   (b) Change mark between pre- and post-test marks;
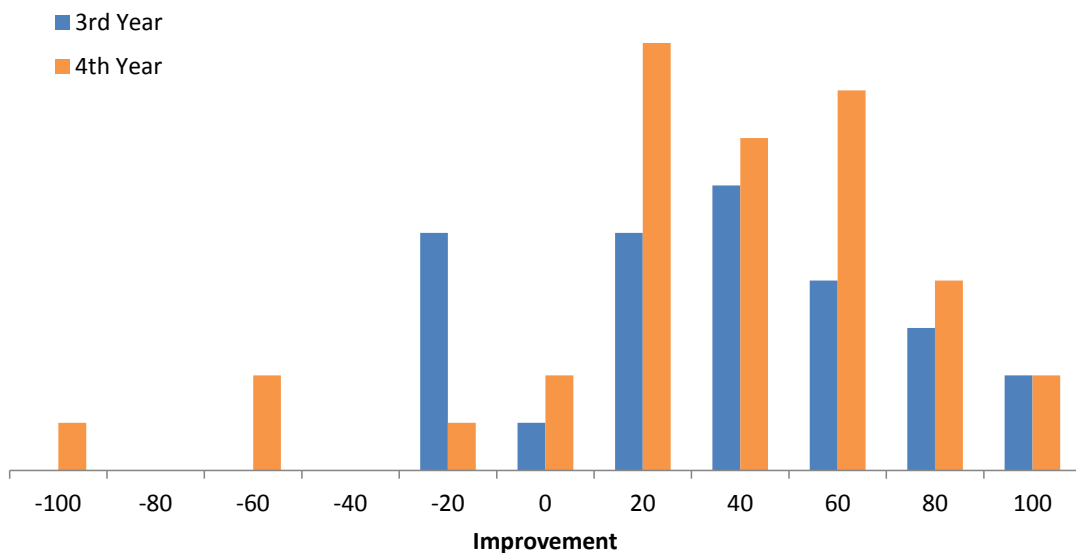
Figure 3.4: Histograms of MCQ diagnostics

Figure 3.5: Histograms of student improvement

Deeper Analysis

As a result of the unusual pattern of results observed, a detailed analysis of the MCQ results was developed. This analysis is based on the premise that material that is truly known and understood by the student will be answered correctly in both the pre- (P1) and post-testing (P2). This analysis requires that the answers for individual questions be compared across both tests, and thus is only valid when the pre- and post-tests are the same. (However, it is possible to extend this once the same concepts are examined in a particular question number.) The analysis is as follows:

- P3 = score of questions that were answered correctly both times;
- P1r = P1/P3, ratio of pre-test score to P3 (should be 1.0);
- P2r = P2/P3, ratio of post-test score to P3 (should be 1.0 or more);
- Guess Index: GI = (P1r-1)* P2r+1, this should be 1.0 if no guessing occurred;
- Performance Index: PI = 0.5*(P1 + P2)/GI, a 40% PI is pass.

The results of this deeper analysis are shown in Figure 3.6 below. It can be seen that there is strong evidence of guessing. A guess index of 1.75 indicates that the answers to half of the questions were guessed. As can be seen most students score a GI between 1.0 (no guessing) and 1.75 (50% guessing), with some students scoring far higher (one guessed all questions).
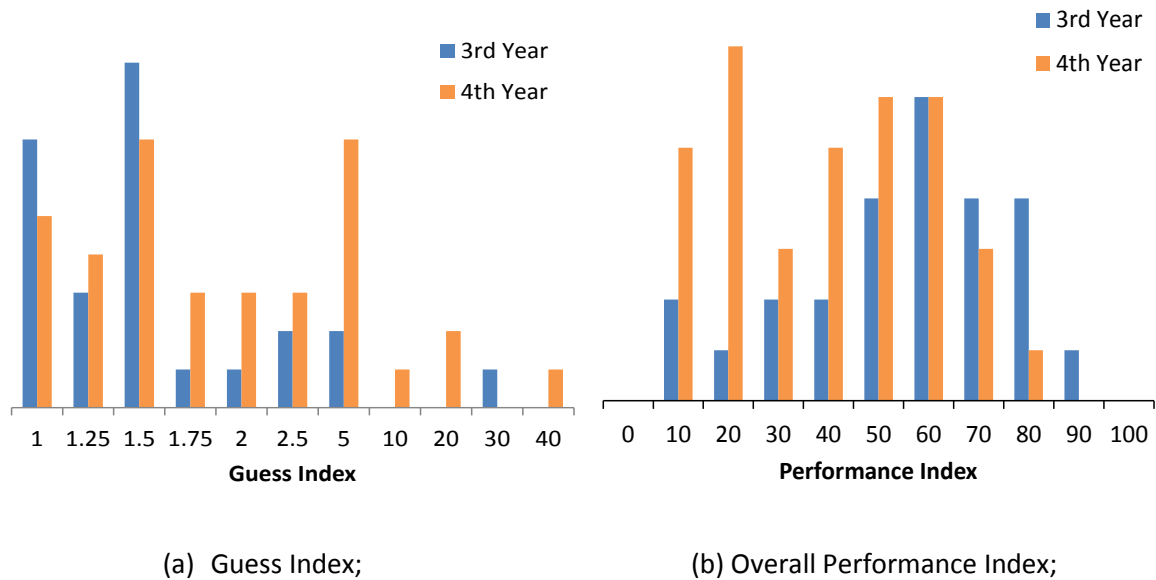

(a) Guess Index;   (b) Overall Performance Index;

Figure 3.6: Histograms of MCQ diagnostics from deeper analysis

In calculating the Performance Index, the Guess Index is used, and so there is an induced dependency between the measures (of exponent -1.0). However, it is still of interest to see if a student's overall performance is related to the amount of guessing carried out that differs to an exponent of -1.0. To this end, each student's GI was plotted against their PI, as shown in Figure 3.7. It is quite clear from this plot that there is a larger than expected negative correlation for the 3rd years (-1.24), and a smaller than expected correlation for the 4th years (-0.2). Thus there is a relationship between performance and guessing, independent of that induced by the metrics used.
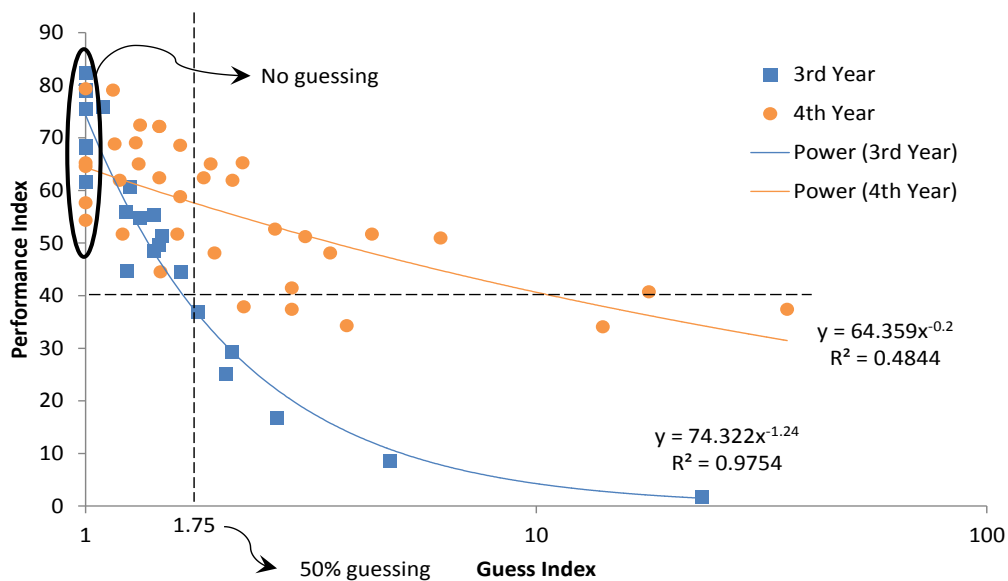

$$y = 64.359x^{-0.2}$$
$$R^2 = 0.4844$$

$$y = 74.322x^{-1.24}$$
$$R^2 = 0.9754$$

Figure 3.7: Correlation between Guess and Performance Indices

From the preceding analysis, it can be concluded that students who guess tend to score less. Of course, it must be realised that the students tested are rational and respond appropriately to the incentives put before them. That they guessed in the testing is therefore a fault of the testing arrangements, and not necessarily reflective of any attempt to deceive on the students' part.

Qualitative Results

The results given so far are solely quantitative. Students' perceptions of the pedagogy undertaken is extremely important, as development of a passion for the subject is critical, yet may take longer to reveal itself. To this end, a randomly selected focus group from each class group was interviewed anonymously by the College Head of Learning Development. The resulting reports are extremely informative, and have already assisted, in liaison with the external examiners, in agreeing detailed changes to the syllabus over second through to fourth year.

In particular, the main findings from the third year focus group were:
- The students felt that a number of the questions could be simply answered by eliminating some of the answer options which they felt were not very realistic and therefore a proper understanding of the concepts was not required to answer some of the questions.
- For the students, the pre-test did reveal the gaps in their understanding, even if their score did not reflect this level of understanding. This helped them to assess their own level of understanding and recognize areas that they needed to work on.
- Overall the students felt the test was too easy and that a thorough understanding of the module content was not really required to do well in the test.
- The students enjoyed the module and appreciated the different learning activities. The projects helped students to link theory to practice, and they spoke of the positive aspects of being able to actually build a model and see the theory in practice.

And the main findings of the fourth year focus group were:
- The students believed that the way negative marking was used encouraged them to guess, even when they were reluctant to do so.
- The students felt that the "phrasing of a number of the questions was ambiguous", i.e. they were unsure of what they were being asked to do or solve.
- The questions in the pre-test were primarily assessing the knowledge covered in the first six weeks (i.e. in the lectures) and not what was "covered" in the second section. Therefore, although the students believed the software had helped them to learn and reinforce the knowledge and understanding from the lectures and notes, they did not feel that this would be reflected in the second test.
- The students were aware that the purpose of using the software was to enhance their learning and reinforce their understanding and felt it was an ideal tool to help them study.
- Overall the students were happy with the module and felt the pedagogy was effective. Positive aspects of the lectures include a high level of interaction (both student–lecturer and student–student), problem-solving opportunities, and the lecture notes (also available from the lecturer's website).

Project Evaluation

Based on both the quantitative and qualitative results, a good improvement generally was shown both in actual marks, but also in conceptual understanding and appreciation of the subject. However, given the interesting results regarding guesswork, it seems that MCQs may not be suitable for the problems at hand. At a minimum, both third and fourth year groups agree that the questions should be redesigned for future use to remove obvious answers and to clarify exactly what is being asked. The fourth year group finding that MCQs with negative marking incentivised guessing is not consistent with established pedagogical findings. This is worthy of further exploration.

Throughout the process, good effort was put into explaining to the students the purpose of the tests. It was made clear that the tests were not to evaluate their knowledge, but to evaluate the effectiveness of the pedagogy. As a result, the students were very positive, helpful, and open to the process: they saw clearly that they would benefit from the information gained from the project.

Recommendations to the College

From the results established here, it is possible to recommend the following:
- Students are very open to facilitating and actively engaging with projects whose aim it is to help them learn more effectively.
- Students are very keen to link mathematical models and physical reality, as they recognize its importance to structural engineering. This should be facilitated wherever possible across the programme.
- The use of MCQs in structural engineering requires further development and better design to enable quick assessment of conceptual understanding.

Proposed Future Activities

From the analysis presented here it is clear that the MCQs need to be redesigned to better measure their intended outcome. In contrast (and perhaps in spite of the quantitative shortcomings), it was found that the pedagogical interventions were effective in enthusing the students and helping them better link mathematical models and physical reality. Clearly then, the interventions established for this Fellowship, ought to be maintained and extended where possible. This will include an evaluation of physical intuition at second year, and examination of introducing a problem-based learning element required physical intuition into first year.

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