A Knowledge Framework for Analysis of Engineering Mechanics Exams

Thomas Goldfinch
University of Wollongong, Wollongong, Australia
tom_goldfinch@uow.edu.au

Anna L Carew
University of Tasmania, Launceston, Australia
anna.carew@utas.edu.au

Timothy J McCarthy
University of Wollongong, Wollongong, Australia
tim_mccarthy@uow.edu.au

Abstract: *In an ongoing research project focusing on improving learning in first year engineering mechanics, a framework for engineering mechanics knowledge has been identified. The framework has been applied to break down and categorise common mistakes made by students at four separate institutions to find out where students are struggling in their efforts to learn statics and dynamics. The framework separates knowledge into factual, procedural, conceptual, and principle areas in a semi hierarchical manner. In using this framework, it has become clearly evident that the marks students are awarded for their work tend to be biased towards procedural knowledge, rather than conceptual knowledge as one might expect for an introductory course. The implication here is that students make most of their mistakes in the problem solving procedures for which most marks are awarded. We propose in our efforts to encourage a deep conceptual understanding needed for further study in engineering mechanics, we may be inadvertently encouraging surface procedural knowledge memorisation.*

Introduction

Researchers and academics from the University of Wollongong, University of Tasmania, and the University of Technology, Sydney are currently undertaking a collaborative research project funded by the Australian Learning and Teaching Council. The project aims to develop an evidence based approach to prescribing alternative teaching methods for educators and learning resources for students of introductory engineering mechanics. Very early in the project it was agreed that substantial quantitative evidence needed to be collected on common mistakes made by students from a first hand source (Goldfinch et al., 2008). These mistakes would need to be analysed and appropriately categorised, and documented to form a solid and objective starting point for the rest of the project. The researchers intended to develop an analytical framework for this part of the research to ensure the identification of common errors made by students was consistent across the four institutions. Use of a standard framework was also necessary to ensure the analysis was not overly influenced by the researchers' own opinions on, and experiences of teaching mechanics. The search for an appropriate framework to structure this work revealed a semi-hierarchical knowledge framework that had been developed by Romiszowski (1981). Students' work in over 200 statics and dynamics final exam transcripts was analysed using a modified version of the Romiszowski framework.

The Framework

The search for an ideal research framework considered a number of different options. Blooms Taxonomy (Bloom, 1961), and its later revision by Anderson and Krathwohl (2001), were obvious starting points as they are widely used in educational research and design. It was felt that these verb based taxonomies, and others aimed at analyzing discursive responses (Biggs & Collis, 1982; Mosely et al., 2005) were not well suited to the heavily mathematical calculation and diagrammatic nature of responses required in statics and dynamics exam transcripts. The search shifted to more mathematically oriented frameworks (Sharp & Zachary, 2004; Van Hiele, 1986) until the Romiszowski knowledge schema was identified. This framework was judged well suited to engineering assessment applications as scientific and mathematical ideas in were considered in the frameworks design from the outset. This Framework also fitted in with the nature of questions in the final examinations which were to be analysed.

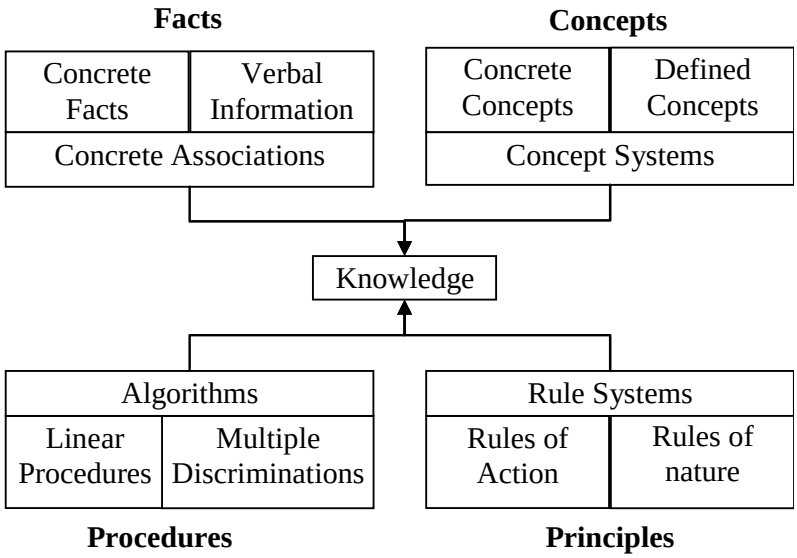

Figure 1: Modified Romiszowski Mechanics Framework (MRMF)

In this case, the first author developed a simplified application of Romiszowski's framework which splits knowledge into four basic categories with three subcategories in each. The original version of this framework also separates the four basic categories into two groups. Facts and Procedures are grouped into ‘Factual Information’, Concepts and Principles are grouped into ‘Conceptual Information’. It was felt that these two top level categories created an unnecessary additional category which did not provide enough fine detail to work with in our case. The duplication of nomenclature in these top level categories may also create confusion over which level was being referred to, particularly in the case of ‘Concepts’ and ‘Facts’. The Modified Romiszowski Mechanics Framework (MRMF) is most easily seen in Figure 1. A basic description of each of these sub-fields in the context of introductory engineering mechanics was developed by the first author and is presented in Table 1.

Table 1: Definition of framework fields adapted to engineering mechanics from Romiszowski (1981)

Category	Sub-category	Definition and example
Facts	Concrete Facts	Things committed to memory from simple observations, and not associated with language. Eg. remembering someone's face, recognition of an object
	Verbal Information	Knowledge associated with language or symbols. Eg. units, terminology, vector notation etc.
	Concrete Associations	Interlinking of facts. Eg. recognizing a truss analysis problem, knowing which given quantity is velocity etc.
Concepts	Concrete Concepts	Simple concrete facts tied to understanding. Eg. recognizing a cantilever beam
	Defined Concepts	More complex verbal and factual information tied to understanding. Eg. Knowing that a vector has magnitude and direction and the associated terminology
	Concept Systems	Interrelated concepts. Eg. momentum is a product of mass and velocity which in turn require understanding.
Procedures	Linear Procedures	Simple, chain calculations. Eg. substituting numbers into an equation and solving.
	Multiple Discriminations	Distinguishing between information, and solving problems in parallel. Eg. knowing/deciding which numbers to substitute into an equation.
	Algorithms	Complete procedures involving both linear procedures and multiple discriminations. Eg. Truss analysis where several problems need to be solved simultaneously using the correct data and processes.
Principles	Rules of Action	Rule's governing the behaviour or actions of the individual. Eg. identifying all given information a the start of a problem solution.
	Rules of Nature	Rules that explain the behaviour of objects or the surrounding environment. Eg. Gravity is what pulls objects down, forces cause the motion of objects.
	Rule Systems	Strategies and theories. Eg, a particular approach to solving a large problem.

Application of the Framework

The application of this framework to analyse students' responses in statics and dynamics exam transcripts was undertaken in several stages. First, each exam paper was answered by one of the researchers with finely detailed notes on each questions' solution carefully noted. Second, these solution notes were placed into a matrix based around the framework. These two steps were then undertaken by two other researchers as a means of comparing the application and interpretation of the framework. From this, it became evident that the framework was open to some interpretation as the three matrices differed slightly from each other, though all three interpretations were in agreement in the majority of questions. The fact that the differences were so slight given the potentially subjective nature this qualitative process showed how well suited this particular framework was for the engineering mechanics application. The slight differences were considered, and the matrix adjusted accordingly. Finally, exam transcripts from four institutions were analysed by one researcher. Repetition of this analysis by multiple researchers would have been desirable, however, funding and academic workload constraints meant this was not possible. Errors made by each student were

recorded in a large spreadsheet based on the framework matrix. These matrices were set up for each institution and kept separate to facilitate comparison of results later on in the research.

It is important to point out that where solution steps were placed in the framework matrix was heavily influenced by the nature of the question. For instance, when considering Newton's laws of motion, one might reasonably assume that these belong in the conceptual knowledge category. However, in one question, students were asked to state Newton's laws of motion. The researcher reasoned that recitation of the laws did not necessitate true understanding of the laws, as students could still achieve full marks by simply memorising them as given facts. Thus the solution to this question was placed in the Factual knowledge field.

Quantifying Mistakes

Using this particular framework to break down and quantifying mistakes proved to be immensely useful to the research project. Since the use of this framework encouraged a fine grained approach to breaking down the solution to a given problem, problem areas were identified that had not previously been considered. Many of these newly recognized problems were due to students lacking a particular piece of assumed knowledge, or students having a fundamental misunderstanding of the given question. In one instance, the problem identified was a simple assumption that students would know that a cable cannot carry a compression force. In another, it was assumed students would know that the impact (or 'final', as is standard notation in a projectile motion question) velocity in a projectile motion analysis was not zero.

In addition to identifying new issues, well recognised problem areas were now supported with quantitative evidence. The analysis also showed that several issues that are anecdotally regarded as quite universal problem areas in engineering mechanics did not present as major issues at some institutions. Shear force diagrams are a good example of this where the magnitude of mistakes made by students varied substantially between institutions.

The overall result of applying this particular framework to quantify mistakes was a clear, and very detailed summary of what students were having trouble with as indicated by final examinations. The statistics from the research are now being used to prioritise what topics in statics and dynamics the research project addresses first and in what detail.

Findings

After analysing the exam questions, and students' exam transcripts with this framework, we discovered a strong emphasis in all the exams on procedural knowledge. The percentage of total errors recorded from exam transcripts at each of the four institutions is presented in Table 2.

Table 2: Proportion of total errors assigned to each knowledge category

Institution	Factual	Procedural	Conceptual	Principle
One	12.52%	45.42%	32.34%	9.72%
Two	8.40%	63.95%	20.25%	7.41%
Three	10.24%	51.06%	24.59%	14.12%
Four	12.53%	45.27%	28.24%	13.96%

It is reasonable to assume that introductory engineering statics and dynamics courses would place emphasis on understanding of the mechanics concepts and principles that will be used in later studies, particularly considering the sheer volume of research publication describing importance of 'conceptual' understanding (Duit, 2007; Flores Camacho et al., 2004). However, the researchers have noted that a large proportion of the marks awarded to students in the exams analysed were based on procedural knowledge. It was subsequently evident in many exam transcripts that students were going through an analysis procedure, and getting stuck at points where deeper understanding of the problem

presented was necessary. This would suggest that students were more focused on the procedure of solving the problem, rather than understanding and analyzing it.

Discussion

Considering the findings of this research, it would seem that first year mechanics final examinations, or at least those analysed, could be improved using a simple knowledge framework. It was an interesting discovery for the academics involved to find that their exams were not always assessing students in the way they had expected (Goldfinch et al., 2008). It is conceivable that the emphasis on procedural knowledge may have been encouraging students to study problem solving procedures in engineering mechanics to pass exams given the exams appeared biased towards this type of knowledge.

By applying this framework at the examination design stage, it seems possible to improve the accuracy of examinations, and target the specific knowledge areas desired by the course coordinator. As this framework presents conceptual knowledge as facts tied to understanding, a greater emphasis on conceptual knowledge in all mechanics assessment tasks could lead to improvements in long term retention of key ideas.

Having this initial data set based on the framework will provide a starting point for further research into the way students respond to exam questions and other assessment tasks. It is hoped that we can use this information to carefully design exam papers in finer detail, and report on any changes in learning outcomes as a result. In doing this, there are certainly improvements to be made in the design, clarity, and application of the framework. However, as we have discovered, the more often it is used and debated, the more useful and efficient the framework seems to become.

Conclusion

A useful framework for the design and analysis of engineering mechanics assessments has been presented here. The application of this framework to existing exam papers and transcripts has uncovered an emphasis on procedural knowledge in introductory engineering mechanics assessments. By using a structured and explicit framework to carefully design assessments, it may be possible to encourage students to study for a deeper conceptual understanding of the important foundational topics of introductory engineering mechanics courses.

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