THE INFLUENCE OF WORKING MEMORY AND PRACTICE ON STUDENT SUCCESS IN ENGINEERING MATHEMATICS

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STRUCTURED ABSTRACT

BACKGROUND

The teaching of mathematics in engineering courses has been problematic. There are many reasons for this, not least of which is the lack of preparedness of students entering engineering studies. This paper gives the results of a pilot study which aims to mitigate this situation

PURPOSE

The purpose of this study was to make use of the latest knowledge in human cognition to improve the mathematics outcomes of engineering students. In particular it makes use of two concepts, working memory limitation and practice, to improve mathematics outcomes.

DESIGN/METHOD

The study was run over two semesters with the first year students who were studying Engineering Mathematics 1 on the Bachelor of Engineering Technology (BET) program at the Manukau Institute of Technology (MIT). The teaching of the course was structured so as to take the students' working memories into account and in such a way as to make use of the modern ideas on students' practice with the mathematical material. The students were assessed at the start of the course and then again at the end of the course. The effect size of the student improvement was then evaluated.

RESULTS

The paper shows that this pilot study indicates that taking working memory and structured practice into account the outcomes of the students were enhanced. Numerical data is presented to support this conclusion.

CONCLUSION

Although the results of this pilot study were encouraging the study used relatively small student numbers (a total of 22 students) and therefore needs to be repeated: preferably by a different polytech. In addition the study highlights some structural problems with the Engineering Mathematics 1 curriculum that are resistant to improving with modified teaching techniques. The paper therefore makes some recommendations on how the overall curriculum should be developed.

KEY WORDS

Mathematics teaching, working memory, practice based learning.

Introduction to Memory Systems

Mathematics in engineering is not just used for calculations but also as a language for teaching advanced concepts. However, for mathematics to be effective as a teaching language is must not consume excessive amounts of working memory when it is being used as a language.

Working memory is the part of the human memory system that is used for conscious awareness, for thinking, and is the place where the first steps to learning something new occur (Baddeley, 2004). However, it is limited to being able to hold approximately seven independent items in its storage at a time (Baddeley, 2004). Therefore when mathematics is used as a language for explaining advanced concepts the learner must be able to use the mathematics 'language' in a fluid and automatic way. If the learner consumes working memory with trying to recall mathematics structures and procedures she will not have sufficient working memory available to apply to the new concepts that she is currently being taught (Cumming and Elkins1999).

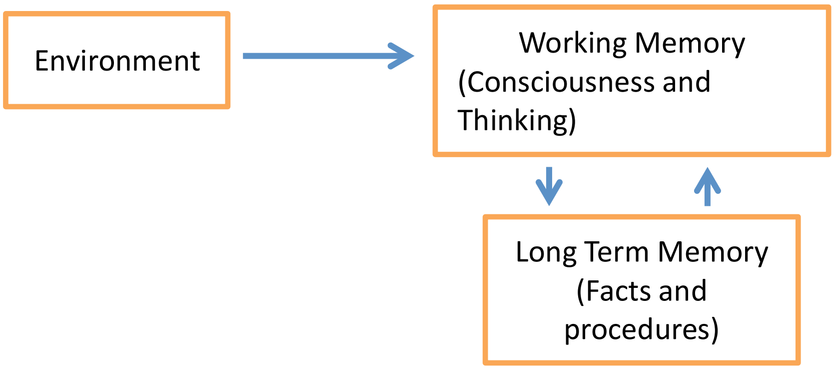

Figure 1: Simplified diagram of the human memory system

(Adapted from Willingham, 2009)

The limitations of working memory can be overcome by placing facts and procedures into long term memory (see Figure 1). The information in long term memory can then be rapidly recalled if the person is well practiced and familiar with the material. Under these conditions recall from long term memory is subconscious, automatic, and fast. This rapid automatic recall of knowledge from the long term memory enables the learning of new material to be easier, quicker, and more extensive because the working memory can be used predominantly for the new material. It is not consumed by trying to recall material that the learner has already learnt (Barclay, Bransford, Franks, McCarrel, and Nitsch 1974).

The way that material is placed in long term memory and is made available for rapid, automatic, subconscious recall is by the learner having extensive practice with the material.

Experts

In order to appreciate the amount of practice required to become expert in a cognitive area the work of Ericson, Kampe, and Tesch-Romer (1993) is most informative. They studied many types of experts; for example national level chess players, and concluded that it takes approximately 10 000 hours of directed practice to become an expert in a particular field (see Figure 2 below for violinists' practice time). The key characteristic of an expert is that she is able to see the solution to a problem rapidly and almost subconsciously, i.e. without having to use extensive amounts of working memory. In addition, an expert has the ability to concentrate during extended practice and this ability is learnt and is not innate (Brown, Roediger III, McDaniel, 2014).

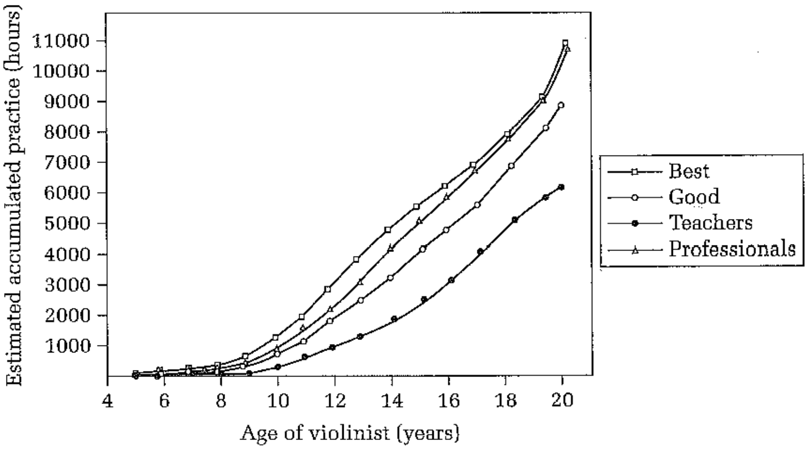

Figure 2: Ericson's data for violinists' practice time (Ericson, et.al., 1993)

The research on experts has implications for lecturing because lecturers are experts and can call on extensive fluid, automatic long term knowledge which they can access rapidly and mostly subconsciously. It is easy for lecturers to forget that students do not have this long term knowledge or if they do they are not able to access it rapidly and fluidly without consuming significant amounts of working memory. Therefore it is easy for lecturers to overload the working memory of learners making the learning of new material an onerous proposition (Willingham, 2009).

Practice

In order for practice to be effective the following factors should be considered:

- Learners need to practice beyond perfection (Bahrick and Hall, 1991). For example if a musician is trying to learn a piece of music it is not sufficient to practice the piece until she can play it through without errors. Once a piece can be played faultlessly it is still necessary to continue practicing the piece so that it gets placed in long term memory and can be fluidly and rapidly recalled.
- In order for material to stay in long term memory for a significant period of time, i.e. in excess of a decade, it is necessary to use the material regularly for three to four years (Ellis, Semb, and Cole, 1998; Bahrick, and Hall, 1991).
- For practice to be effective it is necessary that it be undertaken with concentration, feedback, and a goal in mind (Kang, McDermott, and Roediger, 2007; Gladwell, 2008).
- Practice that is distributed is more effective than lumped practice, i.e. practice that is spread over a number of weeks is more effective than practice that takes place all at one time (Soderstrom and Bjork, 2014).
- Students need to think about the material when practicing because what one thinks about one tends to remember (Willingham, 2009).

- Other ideas to consider are: practice basic material when doing more advanced work, put older work in current assignments, teach students how to practice and do not assume that they already know how to practice material (Brown, et.al., 2014).

The results of effective practice are the following:

- Practice makes the recall of material fluid, automatic, and unconscious which in turn frees up working memory for learning new material (Alexander, Kulikowich, and Schulze, 1994).
- Practice improves the chances of a learner seeing the deep structure of a topic and reduces superficial learning. It is unlikely that a student that does not have a fluid access to the material in a particular topic will be able to appreciate the deep structure of that topic (Schacter, 2002).

Pilot Study of Practice at the Manukau Institute of Technology

In order to test the above ideas in the context of a three year engineering degree at a New Zealand polytech a pilot study was undertaken into the teaching of first year mathematics in the three year BTech degree. The study involved 22 students from the second semester in 2013 and the first semester in 2014.

In the first week of the semester the students were given a diagnostic test to evaluate their mathematical knowledge at the start of their degree studies. The diagnostic test was based on the school year-eleven mathematics syllabus and involved material that students entering a three year engineering degree should know well and have no difficulty with (the mathematics entry requirement for the three year engineering degree is school year-thirteen mathematics). Examples of the diagnostic test material are given in Appendix 2.

The students then undertook the Engineering Mathematics 1 (141.514) course at the Manukau Institute of Technology (MIT). This course involves the students meeting for six hours per week over twelve weeks. Four hours are used for lectures and worked examples presented by the lecturer. Two hours per week are allocated to tutorials. The students are expected to do at least four to five hours of work in their own time each week. Previously this course was assessed via three class tests (50% in total) during the semester in week 6 week 10, and week 12; and via a final examination (50%). Tutorials were run each week however these were merely formative and did not count towards the students' final marks. For this study this assessment regime was modified as follows.

In order for the students to be able to practice the material covered in lectures an online mathematics learning package created by Pearsons, MyMathLab Global, was used. Each week the students had to complete an online tutorial consisting of 20 – 40 questions on the material covered in the lectures. In total the students undertook eleven of these tutorials and in order to encourage the students to complete the tutorials each tutorial was allocated 1 or 2 percent of the final course mark. The eleven tutorials, in total, comprised 15% of the final mark. In addition to the tutorials the students were given three class tests which comprised 35% of their final mark and a final examination which comprised the remaining 50% of the course mark.

The online tutorials were done in a collaborative environment, i.e. the students could help each other with the problems and get help from an MIT tutor. In addition the software package enabled the students to access worked examples similar to the problem they were working on and enabled the students to access a hint routine that gave the students hints on how to do the problems. The students could do each tutorial as many times as they wished and their highest mark was used in the calculation of the 15% total mark. In addition, because the tutorials were Web based, the students could access them remotely using an ID and password. The students could then work on the tutorials at home and get assistance from friends, family members, etc. The aim of these tutorials was to give the students practice in all the mathematical procedures covered in the lectures so that these procedures would become fluid and automatic, i.e. so that the students would not have to use extensive amounts of working memory when they came to use these procedures in other subjects.

In addition, the students were given three class tests based on the quizzes. These class tests were done in a controlled environment, i.e. the tests had to be completed in a specific time, they had to be done individually, and no communication was allowed between the students.

Results of the Pilot Study

The full results are given in the appendix and consist of a comparison between the results of the diagnostic test and the final examination results.

The final examination was more advanced than the diagnostic test so the results under estimate the student improvement because the comparison is between the diagnostic test and a more advanced final examination. If the comparison had been between two similar diagnostic tests the student improvement shown would probably have been greater.

For example, the final examination included complex numbers, matrices, calculus, and differential equations. None of which were in the diagnostic test. This approach, comparing the diagnostic test with the final examination, was adopted in order to comply with the requirements of the ethical committee at MIT.

A summary of the results obtained are as follows:

Table 1: Summary of results

	Diagnostic Test	Final Examination
Assessment average	43.2	62.8
Assessment standard deviation	28.6	25.0
Combined standard deviation	28.3	
Overall effect size	0.69	

According to Hattie (2009) an effect size of 0.4 in the educational field is regarded as good and anything above 0.4 shows that a significant change has taken place. As shown in the Appendix 1, 9 out of 22 of the individual students achieved effect sizes greater than 1.0, i.e. their marks improved by more than one standard deviation (28.3%). Two students showed no significant change in their marks, and two students showed reductions in their marks.

These significant effect sizes provide further evidence for the hypothesis that practice is important for improving mathematics marks and it will be interesting to see if the lecturers of the engineering subjects that these students go into in later semesters find improved mathematical fluidity and automaticity with these students. That is if these students find it easier to understand explanations of new topics that require mathematical reasoning because they do not have to use up valuable working memory trying to recall mathematical procedures and, instead, they can use their working memory to understand the new concepts being explained. It will be difficult to accurately test this hypothesis because the feedback from lecturers will be purely anecdotal based on their perceptions of the students.

Discussion and Limitations of the Study

This study has a number of limitations. Firstly, it involves a small number of students (22) which means that it needs to be repeated over subsequent semesters and needs to be replicated by other polytechs. In addition, this study was not double blinded partly because of the nature of the study, i.e. it would be difficult to set up double blinding in a study of this nature and partly because the MIT ethical committee has reservations about treating the students in one course differently, i.e. splitting the class in half and teaching each half differently.

Secondly, due to time limitations (the study was run over two semesters of 12 weeks each, i.e. 72 hours in each semester) only one aspect of the student's mathematical short comings could be concentrated on, i.e. the practice quizzes were set up to give the students practice in the basic underlying mathematical procedures. There was not enough time for the students to practice the applications of the mathematics. MIT is about to introduce a second mathematics course which, among other things, will give the students more opportunity to practice applications.

Thirdly, the improvement in the students' marks cannot be entirely attributed to the practice quizzes because the students attended lectures, wrote three class tests, and did their own studying. However, there was a strong correlation between the number of quizzes completed and the final examination mark obtained.

Finally, no comparative data was available for the previous approach to mathematics teaching described above except for anecdotal evidence. Generally the anecdotal evidence given for previous approaches to mathematics teaching has been uniformly bad, i.e. lecturers seem to have found that students did not understand fundamental mathematical procedures and had difficulty with applying mathematics. However, the validity of anecdotal evidence is not very high.

Future Extensions of the Study

This approach of giving the students extensive practice could be applied to the whole engineering program. To do this each subject on the program should be analysed to determine what is the important fundamental knowledge required for the subject, i.e. what material must be known very well and fluidly so that more advanced subjects can be easily taught. The program could then be structured to make sure that this material is regularly practiced as a student moves through the engineering program. That is, the material that is essential for an engineer to know fluidly and automatically is placed in her long term memory in such a way that she is able to access it rapidly and virtually subconsciously.

Finally, future studies will look into the effect of spacing learning and into the interleaving of learning (Brown, et. al., 2014).

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Appendix 1

The following is the complete set of results for all 22 students

BET RESULTS ANALYSIS FOR 2013/2 AND 2014/1

Student No.	Diag Test	Exam	ES
530	6.4	43.8	1.32
337	60.3	37	-0.82
975	69.2	95	0.91
80	94.9	87.1	-0.28
120	75.6	91.7	0.57
514	47.4	76.3	1.02
752	21.1	47.5	0.93
177	35.5	71.3	1.26
610	48.7	83.8	1.24
528	56.6	80.9	0.86
252	81.6	55	-0.94
962	15.8	36.5	0.73
449	3.9	7.1	0.11
569	38.2	90	1.83
964	5.3	40	1.22
125	72.4	69.6	-0.10
906	11.8	39.3	0.97
539	89.5	94.2	0.17
270	38.2	87.5	1.74
158	30.3	30	-0.01
347	13.2	59.2	1.62
607	35.5	59.4	0.84

	Diagnostic Test	Examination
Assessment average	43.2	62.8
Assesssment std. dev.	28.6	25.0
Maximum Mark	94.9	95.0
Minimum Mark	3.9	7.1
Median	38.2	64.5
Combined std. dev.	28.3	
Overall effect size	0.69	
Number of students	22	
Note: all values are in %		

Appendix 2

The following is a selection from the questions used in the diagnostic test:

1. Remove the brackets: $-3(5x-2y)$

2. Evaluate: $\left(\frac{1}{3} \div \frac{1}{6}\right) + \frac{1}{2}$
3. Simplify: $\left(\frac{x}{3}\right)^3 x^3$
4. Factorise: $x^2 + 11x + 28$
5. Solve the equation: $7x - 16 = \frac{2}{3}x + 4$
6. Draw the graph of: $y = x^2 - 3$
7. Find the distance between the points (2, −3) and (5, −1).
8. Calculate the value for $\log_9 9$
9. Write the following as the logarithm of a single number: $\log_4 7 + \log_4 5$

Acknowledgements

I would like to acknowledge the friendly cooperation of the students who took part in this study and MIT for providing the facilities and finances necessary for the study. In addition, I would like to acknowledge Pearson's Publishers for developing the software used in the study. This work was inspired by the writings of Dan Willingham.