Improving engineering students' mathematics skills and analysing their behaviour using ICT-tools.

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INTRODUCTION

Good competency in mathematics is important in science, technology and economy as mathematics can be considered a language of nature and technology and an important methodology for economics and social sciences. Students' mathematics skills have deteriorated in Western countries in recent decades despite the society's understanding of the value of mathematics. Learning outcomes in mathematics are not dependent solely on good teaching, sufficient resources or other external considerations with bearing on learning. Factors that also affect students' learning include their attitudes: orientations, intentions and motivations. As these factors are individual, good teaching should take into account student's different learning styles.

The decline in the students' mathematical skills is recognized by the European Union. The Math-Bridge [1] project 2009-2012 was set up in the eContentplus Programme of the 7th framework program to change this situation. The purpose of the project was to bridge the gap between school mathematics and university mathematics by creating an e-learning platform for online mathematics courses.

Because The Math-Bridge system collects log data of student's behaviour in the system, it makes it possible to track and study their behaviour. Log data contains huge amounts of information but scientific visualization can be used to capture and reveal essential phenomena.

The paper describes the supportive actions taken at Tampere University of Technology (TUT) for the first-year students studying engineering mathematics, the use of information technology in supporting students' mathematics studies, and present results of the analysis, performed using the log data collected by Math-Bridge. The measures taken include the Basic Skill's Test (BST), Mathematics Remedial Instruction (MRI), and student profiling based on students' attitudes on learning. The study specifically describes how MRI was implemented in Math-Bridge and carried out at TUT. The effects of MRI for different learner groups using success indicators, log analysis, and statistical methods are presented and clarified through data visualization.

1 SUPPORTING MEASURES FOR ENGINEERING MATHEMATICS AT TUT

TUT's campus is a community of 10,500 undergraduate and postgraduate students. In 2011 TUT offered 12 Finnish engineering degree programs leading to BSc and MSc degrees. The number of students starting their BSc studies annually is about 700. The Department of Mathematics at TUT is responsible for service teaching for all the engineering study programs.

1.1 Basic Skill's Test

Since 2002 every TUT freshman has participated the Basic Skills' Test (BST) to identify the students lacking mathematical skills. The BST is a computer-aided test with 16 upper secondary school mathematics problems to be solved within 45 minutes. The test implementation is modified from the STACK system (System for Teaching and Assessment using a Computer Algebra Kernel) [2] making it possible to generate problems with slightly different parameters for each student. Moreover, STACK automatically assesses students' inputs and gives immediate feedback. Thus, students get their test results when they complete the test. The BST is conducted in a classroom with a teacher, who can help with technical problems. Calculators and mathematical table booklets are not allowed during the test as the purpose is to measure students' mathematical skills per se. To improve the test's reliability the students have three opportunities to solve each problem. If the proposed solution is wrong, the student is asked to improve the solution. Mathematical syntax is also validated to avoid technical errors. In this study the effectiveness of MRI was examined by organizing a second BST at the end of MRI. It was done on the web and because of this the use of calculators and mathematical table booklets could not be controlled. However, the students were well informed that the results of the BST were not related with their math grades and just used to provide them feedback on the development of their skills. Therefore two BSTs were conducted: BST1 before MRI and BST2 after MRI.

1.2 Learner groups

As a part of the BST students are asked to select their learner profile from one of the following: *Skilful Students, Independent Learners, Surface Oriented Learners, Peer Learners or Students Needing Support.* The division is based on the orientation theories by Ramsden [3], Entwistle, [4] and Yrjönsuuri [5], which were used to discover various attitudes toward studying engineering mathematics [6],[7]. The final goal is to devise didactic adjustments that incorporate this diversity.

1.3 First-year students

The students in this study came from 11 engineering degree programs. The students from the Science and Engineering degree program were excluded because their study program differs from the other programs in the study. Those 154 students, who received less than 7 points on the BST1, were directed to MRI. The breakdown of these students into learner groups is presented in Tables 1 and 2. Table 1 also shows the number of students who passed MRI and finally the number of students out of 154 who participated the first engineering mathematics examination. Surprisingly, from those 40 students who needed support, almost half i.e. 18 students were directed to MRI: only 12 passed MRI, and only 10 of the 18 students participated in the first exam. Of the Skilful Students 14 students (9.1%) were directed to MRI, 12 passed MRI and 9 of the 14 took the first exam. Surprisingly, the drop-out was lowest in the Surface Oriented Learners group. In this group 56 students (36,4%) were directed to MRI, 53 passed MRI, and 50 of the 56 students took part in the first exam. This shows that these students take responsibility for their learning, but they are satisfied with passing the course without deeper learning.

Table 2 shows the mean values of the students' first exam scores in each learner group. The scale is 0-5 (0 =failed, 1-5=passed). The number of participants was reduced from 154 students directed to MRI to 118 students who passed MRI and participated in the engineering mathematics exam. The largest group in the study was the Surface Oriented Learners (42.3%) and the second largest group was the Peer Learners group (31.4%).

*Table 1***.** Students in the Study.

Learner Group	BST Done	BST Failed	BST Failed %	MRI Passed	Students in the Study
Surface Oriented	154	56	36.4%	53	50
Peer Learner	221	50	22.6%	43	37
S.N. Support	40	18	45.0%	12	10
Independent L.	76	16	21.1%	14	12
Skilful S.	135	14	9.1%	12	9
Total	626	154	24.6%	134	118

The mean BST scores for the students in the study are given in fourth column of Table 2 titled BST1. After MRI the students took the second BST as described above. The BST2 results are shown in the fifth column of Table 2. Because the conditions for BST1 and BST2 were different the scores are not directly comparable.

Table 2

BST & Exam Results	Students in the Study				EM1u
Learner Groups	n1	%	BST1	BST2	Grade(0-5)
Surface Oriented	50	42.3 %	4.4	10.9	1.5
Peer Learners	37	31.4 %	4.8	11.4	1.5
S.N. Support	10	8.5 %	3.4	9.6	0.6
Independent L.	12	10.2 %	5.2	12.8	1.3
Skilful Students	9	7.6 %	5.3	12.2	1.9
Total, Mean	118	100 %	4.6	11.2	1.4

1.4 Mathematics Remedial Instruction with Math-Bridge

Those students, who did not pass the BST, i.e., received less than 7 out of 16 points were required to participate in the MRI. MRI is a computer-aided brush-up program that includes 71 upper-secondary school level mathematics problems that must solved. The remedial instruction is based on a pure e-learning scenario in which a student independently solves the given problems within four weeks. MRI implementation is an extension of the STACK system, which generalizes randomly parameterized problems, checks the correctness of students' answers and saves the results in a database. Fall 2011 MRI was for the first time carried out with Math-Bridge. MRI is not a test: students must solve all the exercises to pass.

There are several ways to solve the problems. In the simplest case the student opens a problem and solves it. Then the system gives the student feedback about the correctness of the solution. If the answer is wrong, the student can ask for a new, similar problem. If the problem is difficult for the student to solve, that student can open a model solution, which shows the problem's solution. Then the student will be generated a new, essentially a similar problem to solve. This cycle depicted in Figure 1 may continue several times until the student is able to give the correct solution to the problem. Moreover, specially designed mathematics content from the school, is available in Math-Bridge, which supports the student's studies.

The Math-Bridge system collects log data of the student's behaviour while they are using the system. This data contains information about the students' successes on the STACK exercises, the number of attempts students made to solve a problem, and the number of opening model solutions for the problem before they gave the correct answer, and all the data was with timestamps.

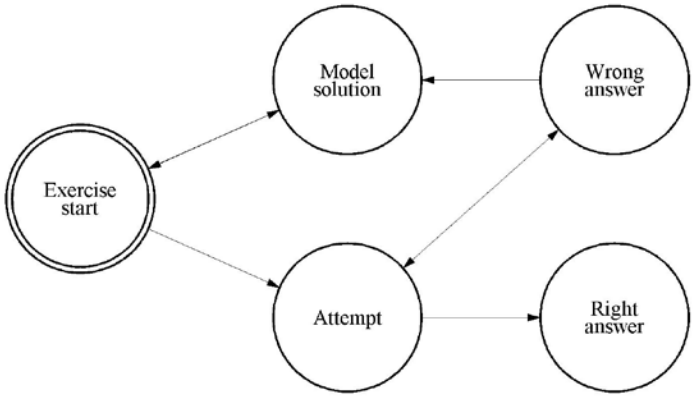


*Figure 1***.** Model of students' behaviour in Math-Bridge exercises.

The Initial log data for those 154 students who were directed to MRI and who completed it successfully were downloaded from the Math-Bridge system. The log data was in a raw form and had to be processed to a data matrix as an Excel worksheet. Some variables were added to the data matrix afterwards. During the study it was found that BST1 and BST2 did not provide sufficient information about the students' mathematical development. Therefore a new variable 'Improvement' was created. It is the difference between BST2 and BST1. Another new variable 'Clicks' is the sum of student's mouse clicks on Start, Attempt and Model Solution. The variable Clicks combined all the student's activity in MRI into only one variable, which made the analysis easier. EM1u (0-5, 0=fail, 5=excellent) represents the grade students received on the first engineering mathematics exam. The correlation matrix between the variables is given in Table 3. A statistically significant correlation with p ≤ 0.5 is represented by * ; if p ≤ 0.1 it is represented by **; and ***represents p ≤ 0.001.

Table 3. Correlation matrix

	BST1	BST2	Improvement	EM1u	Start	Attempt	Model Solution	Clicks
BST1	1.000							
BST2	0.245**	1.000						
Improvement	-0.294**	0.855**	1.000					
EM1u	0.096	0.295**	0.240**	1.000				
Start	-0.033	-0.059	-0.041	-0.058	1.000			
Attempt	-0.085	-0.263**	-0.213*	-0.244**	0.195*	1.000		
Model solution	-0.357***	-0.373***	-0.176	-0.235*	0.217*	0.362***	1.000	
Clicks	-0.222*	-0.314***	-0.190*	-0.240**	0.716***	0.670***	0.738***	1.000

The most surprising observation in Table 3 is the negative correlation between students' activity measured in exercise starts, solution attempts and viewing the model solutions versus the test scores (BSTs and EM1u). This refutes the belief that more work produces better results. This result indicates that when students were uncertain about an exercise solution their log data showed an excessive number of Clicks. These students may have used the trial and error method to solve the problems because they did not have a deep mathematical understanding of the problem. Eventually this will lead to poor performance on tests and exams. The only variables with a statistically significant positive correlation to EM1u are variables BST2 and Improvement. These variables show students' activity but they are also associated with better learning and student commitment.

Another correlation was found between EM1u and the variables Improvement and Clicks. If the students' results improved on the BST2 they received a better grade on the EM1u, but the correlation between Clicks and Improvement was negative. The amount of student work measured in Clicks, did not result in learning, but success on the BST2 did.

Studying in the MRI and thereby improving the BST had a positive impact on the course grade. On the other hand, extraordinary amount of activity during MRI reflected uncertainty and lack of skills, which resulted in a negative correlation between the total number of clicks and EM1u grade.

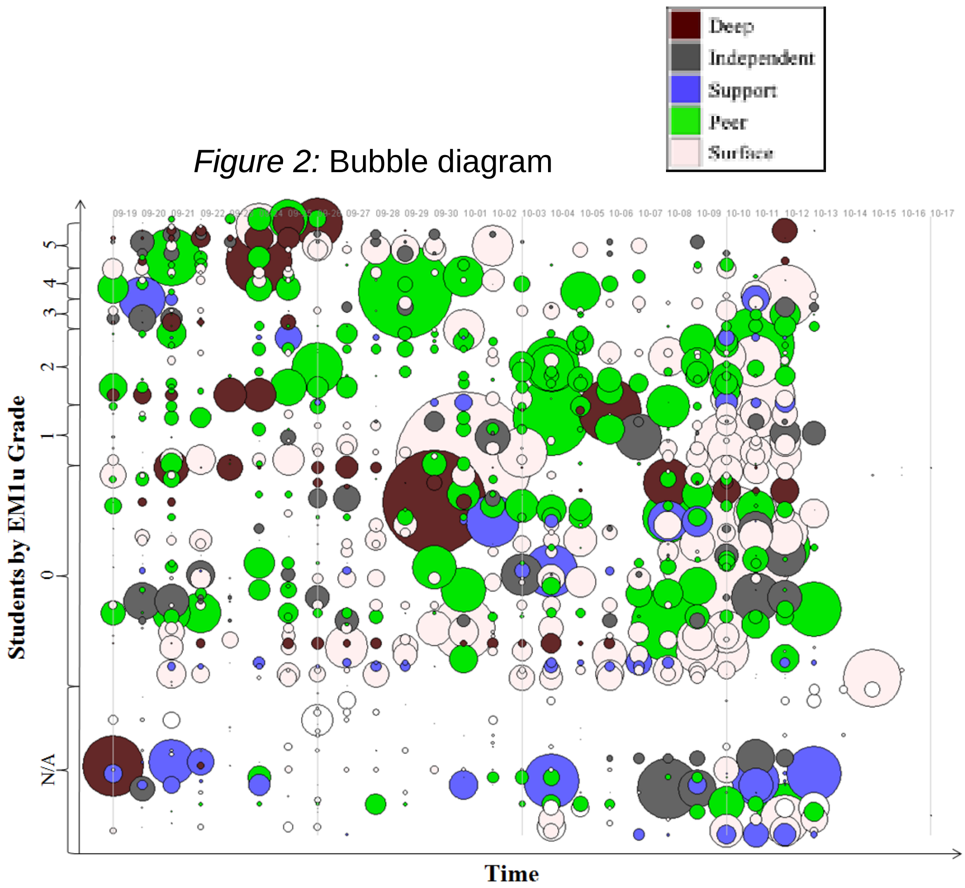
2 LOG DATA VERSUS STUDENTS ACTIVITY DURING MRI

Log data can be analysed using statistical methods, and by plotting various visualizations. In brief, the visualizations are designed to resemble a timeline: Each log item is projected onto a two-dimensional canvas by date and user id, and each item is associated with a small icon that can be used to access the complete log item data. The colour of the icon represents the event type and is associated with a descriptive title. To support navigation, additional shapes were used to provide simple calendar information [8].

2.1 Students' activity as bubble diagram

Students’ daily activities vs. their final grades can be presented as a bubble diagram The timeline is on the horizontal axis, representing the timeframe from beginning of MRI to its completion. Each horizontal row represents the student's activity measured in Clicks. The rows are ordered according to students' grades (0-5) on the engineering mathematics exam. The higher the horizontal row is, the better the student's grade was. The lowest rows represent students who did not pass MRI or did not take the course exam. The size of the bubble reflects the amount of activity measured as Clicks. The bubble colours describe the student's learner profiles.

Figure 2: Bubble diagram



The students who performed poorly tended to perform their activities late (cf. the triangular area on the bottom right with lots of activity), whereas good students tended to perform their activities early (cf. the triangular area on the top left). Most of the activities of students who did not participate in the exam were done by Studens Needing Support (magenta) and Independent Learners (black).

3 CONCLUSIONS

Even though the BST is simple, it seemed to predict students success in their first mathematics course. The BST detected students with weak mathematical skills, as is seen in Table 2. Student learner profiles agree with their success on the BST. Skilful Students received much higher scores than Students Needing Support. The other groups' scores were found in between these two groups' scores.

The usefulness of MRI was studied using correlation analysis. Surprisingly, the amount of work measured as Clicks negatively correlated with students' exam grades. The likely reason is that students who did not know how to solve the problems opened model solutions, guessed and used the trial and error method. Large amounts of clicks reflected students' uncertainty rather than serious work.

The two variables that correlate positively with the exam grades were BST2 and Improvement, which was the difference between BST2 and BST1. As BST2 was done at the end of MRI it reflected the skills recovered or learned, and also students' activity.

Student log events as a function of time revealed the general trend: students who received good course grades seemed to start their work on the MRI at the beginning and finished their work in good time. Students, who did not do so well, finished their MRI just before the deadline.

Future work should include making student activity visible to teachers in real time so that the teachers have the greatest possible impact during the MRI.

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