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Analysing and Improving Students' Mathematics Skills Using ICT-Tools

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ABSTRACT

In this paper the supportive actions taken at Tampere University of Technology (TUT) for the first year students in engineering mathematics are discussed. The measures include Basic Skill's Test (BST), Mathematics Remedial Instruction (MRI), and student profiling based on students' attitudes on learning. Specially, we describe how MRI was implemented in Math-Bridge and carried out at TUT. The effects of MRI for different learner groups using success indicators, log file analysis, and statistical methods are presented and clarified using data visualization.

Keywords: science education, teacher education, biology education, environmental education

INTRODUCTION

Good competency in mathematics is important in science, technology and economy as mathematics can be considered as a language of nature and technology and also an important methodology in economics and social sciences. A study by Hanushek and Wößmann (2007) shows that the quality of education has a strong positive influence on economic growth. In their research, students' skills were measured using 13 international tests that included mathematics, science, and reading.

Despite the fact that the value of mathematics in society and economics is understood, in recent decades students' mathematics skills have deteriorated in western countries. The report "Mathematics for the European Engineer" (2002) by SEFI (The European Society for Engineering Education), Mustoe et.al (2002), states that this phenomenon prevails in Europe. According to the SEFI report, universities in the western world have observed a decline in mathematical proficiency among new university students and have taken action to remedy the situation. The most common measures are: reducing syllabus content – replacing some of the harder material with more revisions of lower level work; developing additional units of study; establishing mathematics support centres; doing nothing.

Learning outcomes in mathematics are not dependent solely on good teaching, sufficient resources or other external considerations with bearing on learning. Factors with bearing on what the student does include attitudes: orientations, intentions and motivations. Orientation describes a student's conscious and unconscious study habits, intention a student's own conscious objective-setting and motivation the will to achieve the objectives set. In order to achieve learning objectives, activity on the part of the learner is required. As student's attitudes and motivational factors are individual, good teaching should take into account student's different learning styles. Students at TUT are classified into Skillful Students, Independent Learners, Surface Oriented Learners, Peer Learners, and Students Needing Support. The division is based on the orientation theories by Ramsden (1984), Entwistle (1986), and Yrjönsuuri (2002), which were used to discover various attitudes to studying engineering mathematics (Huikkola et al., 2008; Pohjolainen et al, 2006).

The decline of the student's mathematical skills is recognized by the European Union. Math-Bridge project 2009-2012 (http://project.math-bridge.org/) was set up in the eContentplus Programme of the 7th framework program to changing this situation. The aim of the project was to bridge the gap between school mathematics and university mathematics by building up an e-learning platform for online courses of mathematics. The system built up during

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Contribution of this paper to the literature

- The main contribution of the paper is in investigating, with variety of methods, the learning processes of the first year engineering students', who were directed to Mathematics Remedial Instruction. The students were grouped by their learning styles based on earlier analysis. MRI was carried out on Math-Bridge-platform that contained the study material and recorded the log data on the students' behavior. A special tool was designed to make the log data visible as time-series bubble diagrams. Students' success in their first exam was investigated using correlation analysis and bubble diagrams. It was noticed that students' activity correlated negatively with exam grade and students, with weak success, started their work late and finished it just before deadline.

the project, is also called Math-Bridge (2017) (http://www.mathbridge. org/). The users of the Math-Bridge system can be grouped as administrators, authors, tutors and learners/students. The Math-Bridge system serves many pre-defined courses, including the option to build courses from thousands of mathematical learning objects. The learning objects include theorems, proofs and definitions as well as instructional examples and interactive exercises. The Math-Bridge system pays attention to a student's individual needs by making it easy to find mathematical learning objects necessary for him/her to study. Because Math-Bridge e-learning system collects log data of student's behaviour in the system, it makes it possible to track and study their behaviour during the courses. Log data contains huge masses of information. Scientific visualization allows capturing essential phenomena and makes it visible for the human eye and brain.

The purpose of this paper is to give a description of the supportive actions taken at Tampere University of Technology (TUT) for the first year students in engineering mathematics, the use of information technology in supporting students' mathematics studies, and present results of an analysis, which was performed to log data collected by Math-Bridge. The measures taken include Basic Skill's Test (BST), Mathematics Remedial Instruction (MRI), and student profiling based on students' attitudes on learning. Specially, we describe how MRI was implemented in Math-Bridge and carried out at TUT. The effects of MRI for different learner groups using success indicators, log file analysis, and statistical methods are presented and clarified using data visualization. This paper is an enlarged version of Pohjolainen et al. (2013).

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 engineering degree programs leading to BSc and MSc degrees in Finnish. The number of students starting their BSc studies annually is about 700. Laboratory of Mathematics at Tampere University of Technology is responsible for service teaching for all the engineering study programs.

Basic Skill's Test

Since 2002 every TUT freshman has participated the Basic Skills' Test (BST) to identify the students lacking mathematical skills. 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) (Sangvin, 2010) 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 right after completing the test. The BST is carried out in classroom with teacher, who can help in technical problems. Calculators and mathematical table booklets are not allowed during the test; the purpose is to measure students' mathematical skills per se. To improve the test's reliability students can try to solve each problem three times. If the proposed solution is wrong, the student is asked to improve the solution. Mathematical syntax will also be validated to avoid technical errors. To find out the effect of MRI a second BST was carried out 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 BST are not related with their math grades and just give them feedback on the development of their skills. So, two BSTs were carried out: BST1 before MRI and BST2 after MRI.

Learner Groups

As a part of the BST students are asked to select their learner profile among *Skillful Students, Independent Learners, Surface Oriented Learners, Peer Learners* or *Students Needing Support*. The division is based on the orientation theories by Ramsden (1984), Entwistle (1986), and Yrjönsuuri (2002), which were used to discover various attitudes to studying engineering mathematics (Huikkola et al., 2008; Pohjolainen et al., 2006). Student questionnaire was

Table 1. Students in this study. The first column shows the learner groups. The second column shows the amount of students in these groups. The third column shows the number of students directed to MRI. The fourth column shows the percentage amount of each learner group directed to MRI. The fifth column shows numbers of students who passed the MRI and the sixth column shows the amount of students who were directed to and passed MRI and participated the first engineering mathematics exam.

Learner group	BST done (n)	BST failed (n)	BST failed (%)	MRI passed (n)	Students in the study (n)
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

Table 2. Engineering math. students in the study by their learner group selections in the beginning of MRI, their amounts (n1), percentages (%), and the corresponding BST mean scores in the first and the second tests (BST1 and BST2). The last column shows their average success in the first Engineering Mathematics course. The grading is 0-5, where 0 means failed and 1-5 passed with grades 1 (satisfactory) to 5 (honours)

BST & Exam results		118 students in the study			EM1u
Learner groups	n1	%	BST1	BST2	Grade (0-5)
Surface Oriented	50	42.4 %	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

performed and analysed with principal component analysis and cluster analysis. The study found meaningful ways to classify students into the above types of learners on the basis of their attitudes.

Skillful Students have a positive attitude to studying mathematics and a positive conception of their own skills. Skillful Students pursue deep learning and do not give up easily. *Independent Learners* do not participate actively in lectures or exercise sessions. They study in their own way and other students have only insignificant influence on the success their studying. They also have a positive conception of their own capabilities. *Surface Oriented Learners* are uncertain about their own expertise. Their attitudes are not the most positive. They do take responsibility for their own learning, but they do not pursue deep learning. Compared to other groups they consider it less important to question what is taught: their intention when studying mathematics is to pass the course and get the degree. *Peer Learners* are more social than the other groups and like to study together with peers. Their attitude to studies is positive. The teacher's support and attention, as well as the examples provided by the teacher are important to them. The attitudes of *Students Needing Support* towards mathematics studies are weak. They hope that someone will come and take them by the hand to advise them. They do not take responsibility for their own learning. Instead they seem uncertain and may easily become alienated to their studies (Huikkola et al., 2008; Pohjolainen et al., 2006). The profiling of the students has been has turned out reliable during many years. The students' distribution into the different learner groups is annually almost identical.

First Year Students

The students in this study come from 11 engineering degree programs. The students from the Science and Engineering degree program were excluded because their study program differs from others. Those 154 students, who got less than 7 points in the BST1, were directed to MRI. The breakdown of these students into learner groups is presented in **Tables 1** and **2**. **Table 1** shows also the number of students who passed MRI and finally the number of students out of 154 who participated the first engineering mathematics examination. A striking figure is that from those 40 Students Needing Support, almost half i.e. 18 students were directed to MRI and from these 12 passed MRI and only 10 students from the 18 participated the first exam. From the opposite, Skillful Students 9.1%, i.e. 14 students, were directed to MRI, 12 passed MRI and 9 students out of 14 took the first exam. Surprisingly, drop-out was smallest in the Surface Oriented Learners group, where 56 students (36.4%) were directed to MRI and 53 passed MRI and 50 out of 56 took part in the first exam. This may reflect the fact that these students take responsibility of their learning, but are satisfied even if they can pass the course without deeper learning.

Table 2 shows the students in the study according to their learner groups and with their mean values of their first exam grades. The scale is 0-5 (0 =failed, 1-5 passed). It should be noticed that the number of students is reduced from 154 students directed to MRI to 118 students who passed MRI and participated the first engineering mathematics exam. The largest group is Surface Oriented Learners (42.4%) and second largest Peer Learners

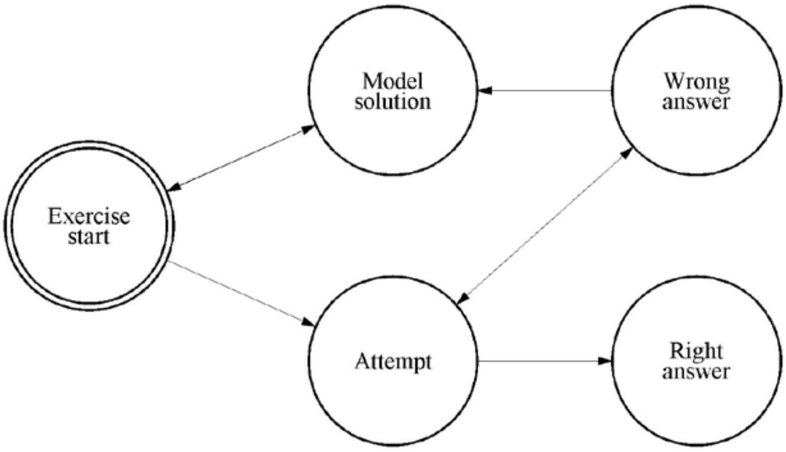

Figure 1. Model of students' behaviour in solving Math-Bridge exercises

(31.4%). **Table 2** presents also the mean scores in BST1 for the 118 students. After MRI the students took the second BST as described above. The results of BST2 are seen as fifth column. As the conditions for BST1 and BST2 were different the scores are not directly comparable. The results of these students in the first exam, i.e. mean values of their grades, are seen in the sixth column.

Mathematics Remedial Instruction with Math-Bridge

Those students, who do not pass the BST, i.e., receive less than 7 points out of 16 must participate in the Mathematics Remedial Instruction. MRI is a computer-aided brush-up program that includes 71 upper secondary school level mathematics problems to be solved. The remedial instruction is based on a pure e-learning scenario where a student independently solves given problems within four weeks. MRI implementation is an extension to 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, as students must solve all the exercises to pass it.

There are several possibilities of solving the problems. In the simplest case student opens a problem and solves it. The system gives her/him feedback about correctness of the solution. If the answer is wrong, she or he can ask for a new but essentially similar problem. If the problem is hard to solve, the student can open a model solution, which shows how the exercise should be solved. After doing this, the student will be generated again a new but essentially a similar problem. This cycle depicted in **Figure 1** may continue several times until the student is able to give the correct solution. Moreover, a specially designed content from school mathematics is available in Math-Bridge for a student to support his/her studies.

Math-Bridge system collects log data of student's behaviour in the system. This data contains information of students' success on STACK-exercises, number of attempts students have tried to solve a problem, number of opening a model solution for the problem before giving correct answer, all with timestamps.

Initial log data was downloaded from the Math-Bridge system for those 154 students who were directed to MRI and who accomplished it successfully. The log data was in a raw form and had to be processed so that finally it was in the form of data matrix as an Excel worksheet. Variables were added afterwards to the data matrix. During the study it was found that BST1 and BST2 did not give sufficient information about students' development. A new variable "Improvement" was created. It is the difference between BST2 and BST1. Another new variable "Clicks" is the sum of student mouse clicks on Start, Attempt and Model Solution. The variable Clicks represents student's activity in MRI with only one variable which make the analysis easier. EM1u (0-5, 0=fail, 5=excellent) is the grade student got from the first engineering mathematics exam. The correlation matrix between the variables is given in **Table 3**. The star * indicates statistically significant correlation with $p \leq 0.5$, ** with $p \leq 0.1$ and *** with $p \leq 0.001$.

The most striking observation in **Table 3** is the negative correlation between students' activity measured in Clicks (exercise starts, solution attempts and viewing the model solutions) against the tests (BST1, BST2 and EM1u). This is in contrast with the belief that more work would give better results. This result may reflect the fact that excessive number of Clicks indicates student's uncertainty in solving exercises, possibly using trial and error method, without deeper mathematical understanding. Eventually this will lead to poor performance in tests and exams. The only variables with statistically significant positive correlation with EM1u are variables BST2 and

Table 3. Correlation matrix on students' activity and their results

	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

Improvement. These variables show student's activity but obviously also can be associated with better learning and student's commitment.

Another parallel observation is seen in the correlation between EM1u and the variables Improvement and Clicks. If the student has improved his/her result on BST2 she/he has got a better grade on Engineering Mathematics 1u, but at the same time the correlation between Clicks and Improvement is negative. The amount of student work measured in Clicks, seems not to account to learning as success as the BST2 does.

Studying in the MRI and thereby improving the BST has had a positive impact on the course grade. On the other hand, extraordinary activities during MRI may reflect uncertainty and lack of skills and that might be the reason why correlation between total number of clicks and EM1u grade is negative.

Log Data versus Students' Activity during MRI

Log data can be analysed using statistical methods, but also by plotting various visualisations. In brief, the visualization is designed to resemble a timeline: Each log item is projected onto a two-dimensional canvas by date and user id, and associated with a small icon using which complete log item data could be accessed. The colour of icon represents event type, and is associated with a descriptive title. To support navigation, additional shapes were used to provide simple calendar information (Nykänen, 2013).

Students' Activity as Bubble Diagram

Students' daily activities vs. final grade can be presented as a bubble diagram. Timeline is on horizontal axis, from beginning of MRI to its end. Each horizontal row represents a single student's activity measured in Clicks.

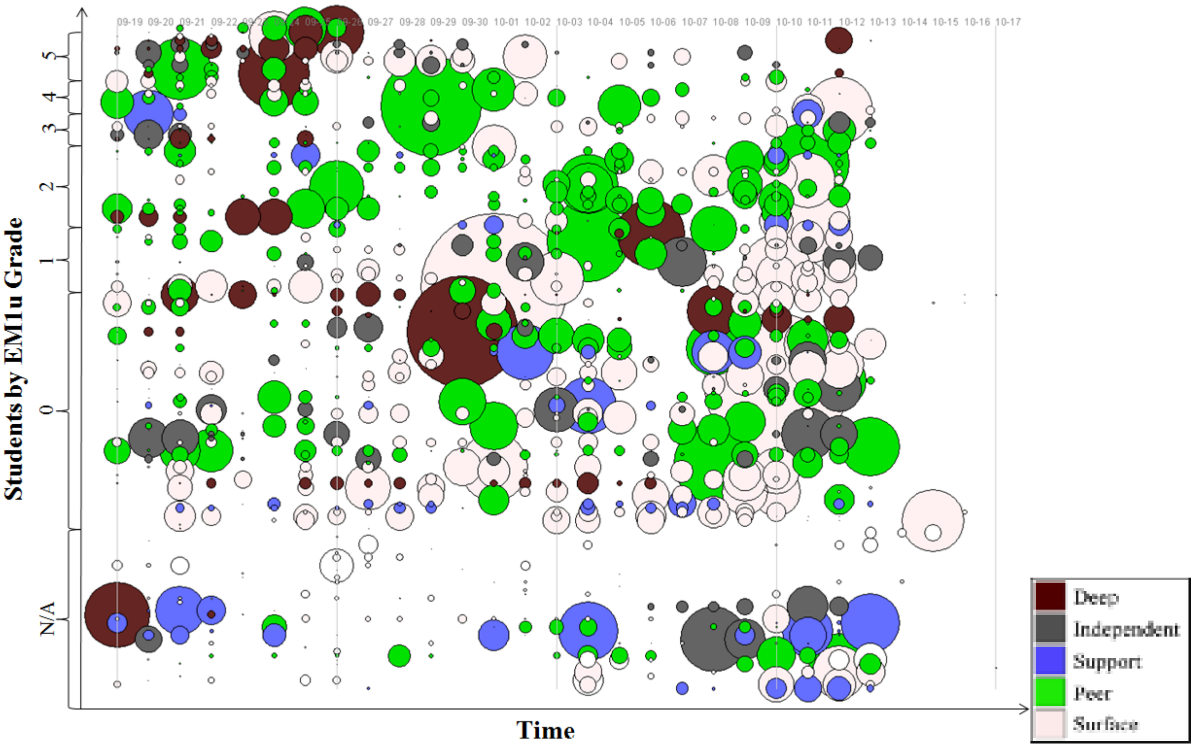

Figure 2. A Bubble diagram of students' daily activities

The rows are ordered according to students' grade (0-5) in the EM1u exam. The higher the horizontal row is, the better the grade is. The lowest row (N/A) is for 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 students' learner profiles.

From **Figure 2** we can observe how the students who perform poorly, tend to perform their activities late (cf. the triangular area on the bottom right, with lots of activities), whereas good students tend to perform their activities early (cf. the triangular area on the top left). Most of the activities of students, who did not participate the exam were done by Students Needing Support (magenta) and Independent Learners (black).

CONCLUSIONS

Even the basic skills' test is simple, it seems to predict students' success in their first mathematics course. Basic skills' test detected students with weak mathematical skills, as is seen from **Table 1**. Student learner profiles agree with their average success in the BST. 90.9 % of Skillful Students passed MRI but only 55.0% of Students Needing Support. Other groups' success rates were between these figures.

Usefulness of MRI was studied with correlation analysis. Surprisingly, it was found out that the amount of work, measured as "Clicks" turned out to correlate negatively with exam grade. The likely reason is that students who did not know how to solve the problems tried to solve them by opening model solutions, guessing and using trial and error method. Large amount of clicks may reflect student's uncertainty rather than her/his serious work. It would have been interesting to see correlation of "Clicks" with their exam grade inside all learner groups. This was not done, because of the small group sizes. The two variables, which correlated positively with the exam grades, are BST2 and Improvement, which was the difference between BST2 and BST1. As BST2 was done at the end of MRI it reflects skills recovered or learned, but also student's activity. Student log events as function of time reveal the general trend: students who got good course degrees seemed to start their work in the MRI early and did main part of their job in good time. Students, who did not do so well, finished MRI just before the deadline.

The observations using the log data were done for the first time. To make the results more reliable the experiment should be repeated during the next years. This would add more data to our analysis and increase reliability of the results. From the pedagogical side the main result stresses the student's activity. Measures are needed to shift a part of the students' activity in the bubble diagram to the left i.e. to start earlier. Future work should include making student activity visible for teachers in real time so that they could intervene the learning process in due course to keep students active.

Finally we would like to point out that correlation analysis or bubble diagrams do not imply causality. Qualitative analysis should be carried out in the future to strengthen and deepen conclusions made in this paper. However, teachers participating in this research could justify our observations and conclusions by their own experience.

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