Aalto University
School of Science
Department of Mathematics and Systems Analysis

Licentiate Thesis

Assessment and learning styles in engineering mathematics education

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May 29, 2012

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ABSTRACT OF THE LICENTIATE THESIS

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School:	School of Science
Department:	Department of Mathematics and Systems Analysis
Professorship:	Mat-1, Mathematics
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Abstract:
At Aalto University School of Science, mathematics teaching has been actively developed since the early 2000s. In this research, the factors that impact first year engineering students' learning outcomes were studied. The factors studied were basic skills in mathematics, computer aided assessment and learning styles.

Automatic assessment system STACK has been used in basic courses of mathematics since 2006. The impacts of automatic assessment to students' learning results were discovered. According to the results, the use of the system has increased the flexibility in mathematics teaching. It also makes it possible to increase the significance of exercises to the course grade.

A Basic Skills Test of mathematics was also implemented by STACK system. The test was based on the similar test developed at Tampere University of Technology. It included 16 questions about upper secondary school advanced mathematics topics. Since 2008, all new engineering students at Aalto University have taken the test at the beginning of their studies. According to the results of the test, students have difficulties for example with understanding the concepts of logarithm.

In the autumns of 2009 and 2010, all new engineering students also had a possibility to answer a questionnaire which was based on Felder and Soloman's Index of Learning Styles Questionnaire. According to the answers, most of the engineering students at Aalto University are visual and sensing learners. In sequential/global and active/reflective dimensions results were more balanced.

The results of this study are going to be considered when developing the engineering mathematics teaching. Some improvements, for example the use of activating teaching methods, have already been done.

Date: May 29, 2012 Language: English Number of pages: 86

Keywords:engineering education, mathematics, teaching, automatic assessment, learning styles

AALTO-YLIOPISTO TEKNIIKAN KORKEAKOULUT PL 11000, 00076 AALTO http://www.aalto.fi	LISENSIAATINTUTKIMUKSEN TIIVISTELMÄ

Tekijä:	Linda Havola
Työn nimi:	Arviointi ja oppimistyylit insinöörimatematiikan opetuksessa
Korkeakoulu:	Perustieteiden korkeakoulu
Laitos:	Matematiikan ja systeemianalyysin laitos
Professuuri:	Mat-1, Matematiikka
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Tiivistelmä:
Aalto-yliopiston perustieteiden korkeakoulussa on aktiivisesti kehitetty matematiikan opetusta 2000-luvun alkupuolelta lähtien. Tässä tutkimuksessa tarkasteltiin ensimmäisen vuoden insinöörialan opiskelijoiden matematiikan opintomenestykseen vaikuttavia tekijöitä. Tarkasteltavia tekijöitä olivat matematiikan lähtötaso, tietokoneavusteinen arviointi ja oppimistyylit.
Automaattisesti tarkastettavien tehtävien STACK-järjestelmä on ollut käytössä Aalto-yliopiston matematiikan peruskursseilla vuodesta 2006 lähtien. Tutkimuksessa tarkasteltiin järjestelmän vaikuttavuutta. Tulosten perusteella järjestelmän käyttö on lisännyt joustavuutta kursseilla. Myös laskuharjoitusten vaikutusta kurssin arvosanaan on voitu lisätä.
STACK-järjestelmää käyttäen toteutettiin myös matematiikan perustaitotesti, joka perustuu Tampereen teknillisessä yliopistossa aikaisemmin käytössä olleisiin kysymyksiin. Testi sisältää 16 kysymystä lukiomatematiikan insinöörialan kannalta tärkeimmistä osa-alueista. Vuodesta 2008 lähtien ensimmäisen vuoden Aalto-yliopiston teknillisten alojen opiskelijat ovat vastanneet perustaitotestiin syksyn alussa. Tulosten perusteella opiskelijoilla on vaikeuksia esimerkiksi logaritmin käsitteen ymmärtämisessä.
Uusilla opiskelijoilla oli mahdollisuus vastata myös syksyinä 2009 ja 2010 oppimistyylikyselyyn, joka perustui Felderin ja Solomanin Index of Learning Styles Questionnaire -kyselyyn. Vastausten perusteella suurin osa Aalto-yliopiston insinöörialojen opiskelijoista on visuaalisia ja aistivia oppijoita. Sarjallinen/globaali ja aktiivinen/reflektiivinen -ulottuvuuksissa opiskelijat olivat jakautuneet tasaisemmin.
Tutkimuksesta saatujen tulosten perusteella on tarkoitus kehittää insinöörialan matematiikan opetusta. Joitakin kehittämistoimenpiteitä, kuten aktivoiven opetusmenetelmien kokeilu, on jo toteutettu.

Päivänmäärä: 29.5.2012	Kieli: englanti	Sivumäärä: 86

Avainsanat:insinöörikoulutus, matematiikka, opetus, tietokoneavusteinen arviointi, oppimistyylit

Acknowledgements

At the time I wrote this thesis, I worked at the Department of Mathematics and Systems Analysis, Aalto University. I was a member of computer aided mathematics teaching research group.

Without the support of the department, I would not have been able to work on this research. I want to thank my supervisor professor Esko Valkeila for the help he gave me during my studies. I am very grateful to my first instructor Dr. Antti Rasila for giving me many valuable comments during the project, and my other instructor Dr. Jorma Joutsenlahti, University of Tampere, for pedagogic advices. I own my thanks also to my dear friend Riikka Korpela for correcting the language of this thesis.

I had also a great opportunity to be an unofficial student in a PhD seminar for doctoral students in mathematics education of University of Helsinki. Thank you professor Makku Hannula for giving me this opportunity and all the members of the seminar for the comments I received.

It was nice to be a part of the working community of the department. Thank you Helle for sharing the office with me and giving lots of advices. Thank you all the other colleagues for the interesting discussions during the time I have worked there.

Finally, my family and friends have been very important during this project. Thank you my mother Raili, father Harri, sister Heidi and brother Henrik for supporting me with my career choises. I own my greatest thanks to my husband Jaakko who has supported me in the good and bad days within all these years.

Espoo, May 29, 2012

Linda Havola

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Chapter 1

Introduction

At Aalto University School of Science mathematics teaching has been an active field of development in the past few years (for example [9, 27, 65, 67, 69]). Teachers have noticed that first year students' skills in mathematics vary and that some students do not actively participate in lectures and exam sessions. Similar problems have also been identified in Finnish secondary school [61] and internationally. For example in his study at Coventry University, Lawson noticed that the entry skills in mathematics of university students have declined over time [47]. At Tampere University of Technology only 57 % of the students who started their engineering studies in 2005 had completed first year mathematics courses by May 2009 [77]. The main motivation of the development project at Aalto University has been to increase the number of students passing compulsory mathematics courses [27]. In order to find the best ways to improve the situation, it is necessary to thoroughly understand the problem. This is the goal of this study.

According to Felder and Brent [20] there are three facets of student diversity: learning styles, approaches to learning and orientations to studying, and intellectual development. Instructors should understand these differences so that they will meet the diverse learning needs of all their students. Many of the instructors believe that the drop-out students are those who are weak and unqualified to become engineers [20]. However, Seymour and Hewitt's study showed that grade distributions of students who leave technical curricula are essentially the same as other students [76].

Teaching methods in mathematics courses at Aalto University have earlier been very traditional. In one course there could be over 200 enrolling students and the course usually consists of traditional mass lectures, different kinds of exercises and midterm exams. In 2006 the automatic assessment system STACK (System for Teaching and Assessment using a Computer Algebra Kernel) was introduced to one basic course in mathematics [65, 67]. After the pilot course the system has been used in nearly all basic mathematics courses [69]. Some certain improvements in students' learning results have been observed thereafter [72].

One area where improvements could be made is the mismatch between the learning styles of engineering students and teaching styles of their teachers [21]. For example, most of the engineering students are visual learners, whereas most of the engineering education is auditory (lectures etc.). Thus, it is useful to study, what the learning styles of Aalto University students are. By using the results of this study it is possible to improve teaching methods so that they would better take account the diversity of students.

In this study, the impacts of automatic assessment to students' learning results are studied. The starting skills of new engineering students are also studied by using automatic assessment. Learning styles are studied as one other factor that affects students' learning. This thesis is organised as a summary and following two articles

1. Havola, Linda: New engineering students' learning styles and basic skills in mathematics. In Silfverberg, H. & Joutsenlahti, J. (eds.) *Tutkimus suuntaamassa 2010-luvun matemaattisten aineiden opetusta. Matematiikan ja luonnontieteiden opetuksen tutkimuksen päivät Tampereella 14.-15.10.2010.*, 118-131, 2011.

2. Rasila, Antti; Havola, Linda; Majander, Helle; Malinen, Jarmo: Automatic assessment in engineering mathematics: evaluation of the impact. In Myller, E. (ed.), *Reflektori 2010 Tekniikan opetuksen symposium 9.-10.12.2010*, 37-45, 2010.

The first article concerns the results of learning styles questionnaire and Basic Skills Test. The research plan for that study is presented in [26]. The second article concerns the automatic assessment system STACK and its impacts to learning results.

Chapter 2

Background

This thesis is a part of a long development process of mathematics teaching at Aalto University (former Helsinki University of Technology). In this chapter, the studies and results of the development of mathematics teaching before author's own work are presented.

2.1 MatTa and MatTaFi projects

Computer aided mathematics teaching has been developed at Helsinki University of Technology since 1980s [37]. The aim of the project that started in 1989 was to find ways to use computers in the teaching of mathematics. The use of computers had just begun to increase in the society, which forced to make changes in the curricula [38]. Classical engineering mathematics problems, like technical blueprints drawn by hands by using descriptive geometry, have been substituted by computer modelling, like CAD. A broad report of computer programs applicable for mathematics teaching was established in 1992 by Petteri Mannersalo [55]. The report includes 249 programs with descriptions of each.

In the years 1993-2003 a project "MatTa" (Matematiikkaa tietokoneavusteisesti, *Mathematics aided by computer*) [42] was led by Simo Kivelä. One aim of this project was to produce digital study materials for revising upper secondary school mathematics before starting engineering studies. On the other hand, the materials of the project could also be used in upper secondary school and university of applied science levels. Another aim of this project was to study pedagogical issues of computer aided study materials [40].

In her Licentiate's thesis in 1995, Loimulahti studied the use of hyper-media in teaching mathematics. At that time, hypermedia-based study materials were produced at Helsinki University of Technology. Loimulahti used MetaCard program to produce HypeMATH study material which is based on constructive learning theory [51, 52]. Constructivism emphasizes the learner's own role in building knowledge [50]. When using hypermedia material the learner's construction process is built on her previous knowledge [52]. MetaCard is no longer available, so these materials are not in use anymore.

Based on the material developed in HypeMATH project, a remedial instruction material of upper secondary school mathematics topics called "$\mathfrak{M}$ niinkuin matematiikka" (abbreviation Iso-M) [44] was developed in the late 1990s. It was used as a self-study material. A 400-page encyclopedia consists of 92 articles that are connected with each other by hyperlinks and 100 exercises.

In MatTa project, many other study materials were also produced, for example DiffEqLab, a MATLAB based package for studying differentially equations at university level [39]. Simo Kivelä piloted the use of DelTa program in the advanced mathematics course L2. The aim of the pilot was to find ways to use the program as a part of a traditional mathematics course, to test its technical usage and to study how students like it. The course required more self study than traditional courses. In addition to summary lectures, the course also included exercise sessions and additional exercises. [41]

There was an unfortunate number of students who did not actively take part in any teaching forms of the course [41]. However, the same has been noticed in other mathematics courses too [68]. Based on the results of inquiries made at the beginning and at the end of the course, students liked computer based teaching methods. On the other hand, they do not want traditional teaching methods to be forgotten either. Some of the students felt the reading of hypertext difficult. A conclusion of this study was that when using computer based teaching methods, computer may not be the substitute of a teacher or a book [41]. After this course, a lot has been done at Aalto University to develop computer-based teaching, and many of the problems perceived in DelTa pilot have been solved thereafter. A complete list of all the materials produced in MatTa project is in page [42].

After the MatTa project ended in 2003, a new project called MatTaFi (Matematiikkaa TietokoneAvusteisesti kansallisesti, *Mathematics aided by computer nationally*) was established in 2004. This project was first led by Simo Kivelä and after 2006 by Dr. Antti Rasila, Helsinki University of Technology, and it had ten universities and universities of applied sciences (for example University of Helsinki and Rovaniemi University of Applied Sciences) as partners. The project was funded by the Ministry of Education and the funding ended in 2007. After that, the activity has been ongoing with smaller volume as founded by partner institutions. Within this project, for example, new e-learning materials (see [66]) and Euler system for storing exercises has been developed.

2.2 E-learning in the course Mathematics 1

In collaboration with German Virtuelle Hochschule Bayern and Finnish Virtual University, an e-learning-based basic mathematics course Mathematics 1 was executed in HUT in 2008. The topics of the course included, for example, linear algebra and calculus. The aim of the international collaboration was to widen the use of the e-learning material that have been developed in HUT. The course was held in English. The target group of this course was international students and those students who are not able to attend traditional basic mathematics course that include more classroom teaching.

The development of the course material was a part of author's Master's thesis work [8]. Web-based lecture notes were written according to Dr. Ville Turunen's and Dr. Pekka Alestalo's earlier lecture notes. Plenty of new automatically assessed STACK exercises were also developed. Unfortunately, only few students took part in this course, but the feedback collected was positive. This course is organised yearly at Aalto University and the same materials have been used as course materials since the project ended.

2.3 Other projects at Aalto University related to mathematics teaching

Besides the development of computer aided e-learning material, also other projects related to the development of mathematics teaching have been carried out at Aalto University. In the early 2000s, regular help for the solving of mathematics and physics exercises, called ”calculating room” (Laskutupa in Finnish), was established. At the beginning this was only small-scale work. Since 2008, there has been an instructor (usually a doctoral student) two to seven hours per day in the classroom helping students. After that the activity has become very popular. Students who take part in this activity tend to get better results from the basic mathematics courses. On the other hand, the results are opposite when examining advanced mathematics students [68]. The reason for these results require more specific studies.

One of the aims of calculating room is to activate students to learn mathematics in collaboration with other students. Activating teaching methods have also been piloted in some basic mathematics courses. In 2010, a brand new Bioproduct technology study program was founded at Aalto University. Also the mathematics courses of this study program were newly planned. The teacher activated students in lecture sessions, for example, by giving short problems to be solved during the lecture. Homework exercises were evaluated by using peer review. The feedback collected from students was very positive, and also students’ learning results were good [28].

Chapter 3

Theoretical framework

In this chapter, two different aspects affecting students' learning in mathematics are presented: learning styles and assessment methods. The ways in which students like to study and to be assessed vary, and it is important to understand these differences.

3.1 Assessment in higher education

The way how students learn depends on how they think they will be assessed. Assessment affects things that students think are important and how they use their time [11] and, therefore, it also affects the learning results. Thus assessment should be aligned with learning outcomes [7]. Exercises that are given to students throughout a course may serve as formative assessment [58]. Feedback could be qualitative, e.g. written feedback, or brief feedback of how student's answer departs from model solution [73]. Exercises provide regular feedback to students in order to stimulate learning [58].

Traditional exams are summative assessment tests. The main purpose of this type of assessment is to make judgement regarding each student's performance [58]. In mathematics, feedback is most often quantitative, e.g. mark or percentage [73].

Mathematics exams often assess only few topics of the course and they do not motivate students on continuous learning during the course.

The regular use of tests and assignments throughout the course is frequently referred to as continuous assessment [58]. Trotter studied the use of continuous assessment in Business taxation course in a UK university. Tutorial files accounted for 10% of the total mark on the module. The results of the study were promising: most of the students found the tutorial files useful. They perceived that their learning improved due to the regular submission of assessed work [80].

Conole and Warburton made a review of computer-assisted assessment (CAA) [16]. Bull and McKenna define CAA as ”the use of computers for assessing student learning” [12]. Sclater and Howie categorize six applications of CAA: credit bearing tests by *formal examinations (1)* or *continuous assessment (2)*, *authentical (3)* or *anonymous (4) self-assessment* and diagnostic testing by *pre-testing (5)* or *post-testing*. [75]. At Aalto University CAA has been used for continuous assessment (2) [53], authentical and anonymous self-assessment (4-5) and diagnostic pre-testing (5) [27].

At Aalto University, automatic assessment system STACK [24, 74, 73] has been used in several basic mathematics courses [53, 69]. The system was used first time at Aalto University in Basic course in mathematics KP3-I in the autumn of 2006. The goal of the pilot course was to test the system in a real course environment. There were both traditional exercise sessions and STACK-exercises in the course. By solving exercises, students could earn extra points which were added to the points of the exam. Students solved STACK-exercises even more actively than traditional exercises. However, there were some technical problems regarding to the entering of complicated answers. Students' final grades seemed to be closely connected to the exercise solving activity [65]. After the pilot course STACK-system has been regularly used at Aalto University in other engineering mathematics courses. More information of the results of these courses are in chapter Results and in [8, 9, 53, 69].

CAA has also been popular in teaching computer science and the impacts of it has been studied, for example, in [3, 32, 78]. The effectiveness of the feedback in CAA has been studied by Gill and Greenhow in [23]. They developed CAA questions that tell students not only that they are wrong but quite precisely where they went wrong. They also provided students a fully worked solution. These kinds of questions have also been developed at Aalto University [71]. The questions that were used in Gill and Greenhow's study were incorporated into an undergraduate mechanics module for the years 2004 and 2005. The evaluation showed that students engage with formative assessment activities even when no marks are allocated. Students were also able to develop their mathematical skills two of the four CAA topics. Thus CAA seems to be an effective tool to provide formative feedback to students [23].

Automatic assessment has also been used for diagnostic testing for new students (for example [6, 47]). Coventry University has used diagnostic testing in mathematics in the years 1991-2001. The results of the multiple choice test showed that entry skills of new students have declined over time [47]. The same results have been noticed in Dutch universities as well [29]. In Heck and van Gastel's study freshmen students took a one-hour diagnostic test which was implemented by automatic assessment system Maple T.A. [2]. However they were also able to hand the answers on scrap paper. They took a second diagnostic test in the fifth week of their studies. Those who did not pass the tests were guided to the remedial teaching of mathematics. Analysis of the results showed that students make computational mistakes even on simple calculations with fractions and algebraic manipulations. Students were appreciated that they were confronted with the mathematics abilities as desired by the universities and were informed about their own level. [29]

3.2 Learning styles

Hartley defined learning style as a way in which individuals characteristically approach different learning tasks [25]. Engineering students' learning styles have been studied for example in [4, 26, 86]. Coffield et al [14] made a critical review of the literature on learning styles. The review identified 71 models of learning styles altogether and 13 of them were analysed. According to the review, a lot of research has been made about learning styles (for example [46, 60]). The review criticized for example the commercialism of some inventories and that models are produced for different purposes [14]. In the domain of psychology, Cassidy [13] made a meta-analysis of 25 different learning style theories, models and measurements.

However, the Felder-Silverman Learning Styles Model (FSLM) that is used in this research is not studied in Coffield et al.'s or Cassidy's analysis. Cassidy claimed that different learning style theories offer approaches with different emphases for investigation [13].

Famous psychiatrist Carl Jung suggested that some aspects of human behaviour can be predicted and classified [18, 33]. The Myers-Briggs Type Indicator personality inventory (MBTI) makes Jung's theory understandable and useful. It classified learners to 16 distinctive personality types [60]. The main preferences were Extraversion or Interversion, Sensing or Intuition, Thinking or Feeling and Judging or Perceiving. One of the most popular learning style model in research is Kolb's Experiential Learning Theory (ELT). ELT model classifies the learning styles in two pairs of dialectically related modes - Concrete Experience (CE) and Abstract Conceptualization (AC), and Reflective Observation (RO) and Active Experimentation (AE) [46, 45].

In Felder and Silverman's Learning Styles Model (FSLM) all four dimensions are combinations of earlier studies and models. It has been widely used in engineering education. The dimensions of the model are sensing-intuitive, visual-verbal (initially auditory), active-reflective, sequential-global and inductive-deductive (see Figure 3.1). The last dimension inductive-deductive has been omitted after some reconsiderations. [21, 79]

Carl Jung has introduced sensing and intuition as two different ways people perceive the world [33]. Sensing learners observe data through the senses. Intuitive learners perceive it by speculation, imagination and hunches. Most of the people tend to favor sensing or intuitive learning, but everyone uses both faculties [21]. Some people are better at processing words and some at processing pictures, which is called the visualizer-verbalizer hypothesis [56]. Most of the people in the college age are visual learners [5].

Active learners work well in groups. Reflective learners work better by themselves or with at most one other person. They do not either learn much in situations which do not enable them to think about the information being presented. Sequential learners master the studying material more or less as it is presented, whereas global learners learn in fits and starts. [21]

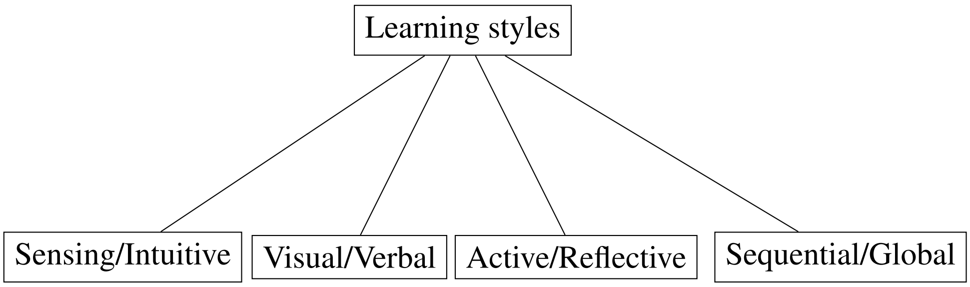

Figure 3.1: Learning style dimensions in Felder and Silverman's Learning Styles Model [79].

Jorma Vainionpää has studied students' experiences of learning on a web-based course organised by The Finnish Virtual University. He also studied the learning styles of communication science students by using Felder and Soloman's Index of Learning Styles questionnaire (ILS) [79, 82]. There are also some web-based elements in mathematics teaching at Aalto University, so these results can be compared with each other. Vainionpää discovered that communication science students tend to be active, visual and global learners. In the sensing/intuitive dimension, results were more balanced. The results were also compared to the learning styles of education students. Communication science students were more global than the education students, and this result was statistically significant [82]. These results were in line with earlier studies [22, 82].

There are many comparisons between learning styles in different countries and cultures (for example [35, 70]). Alaoutinen, Heikkinen and Porras [4] utilized a collaborative teaching concept Code Camp to illustrate the effect of learning styles on the success of a course. The Mobile community services course was arranged both in Finland (15 students) and in Egypt (32 students). The contents, assessment and even the assistants of these courses were the same. Only the lecturers and the length of the camp varied. The learning styles of students were studied by using the ILS questionnaire [79]. Students seemed to be active, intuitive, visual and sequential learners and there was no significant difference between Egyptian and Finnish students. Teaching style of the course seemed to fit the participating group well [4].

Chapter 4

Research questions

In this research, some reasons why students do not pass the basic courses in mathematics are studied. One solution for this problem might be automatic assessment, and thus the impacts of it are studied. By using automatic assessment, the basic skills in mathematics of new engineering students are studied. The differences between the styles students learn may also impact learning results and thus students' learning styles are also studied. The research questions of this study are following:

1. How do the use of the automatic assessment system STACK (System of Teaching and Assessment using Computer Algebra Kernel) impact students' learning results?
   - i How does the amount of students' training with the system impact the scores of the exams?
2. What are the starting skills of mathematics of new engineering students according to the Basic Skills Test of Mathematics?
   - i How well do the starting skills predict success in basic mathematics courses?
   - ii What kind of differences, if any, there are between the results of different years?

iii How do gap years after upper-secondary school impact students' test results?

3. What learning styles do new engineering students at Aalto University have?

   i How well does the learning style the student has predict success in basic mathematics courses?

   ii What kind of differences, if any, there are between the learning styles of engineering students and communication science students?

Chapter 5

Research methods

New engineering students' learning styles and basic skills in mathematics were measured by using quantitative research methods [17]. The impacts of continuous assessment were studied by statistical analysis of the existing data. In this chapter the instruments used in studying the learning styles and basic skills in mathematics are presented.

5.1 Basic Skills Test of Mathematics

All new engineering students of Aalto University took the Basic Skills Test of Mathematics in the autumns of 2008, 2009, 2010 and 2011. The test was organized as a part of a compulsory course for all but architect students, so nearly all students took the test. During the test there was a teacher in the class who answered to technical questions.

The test problems were originally developed at Tampere University of Technology (TUT), but the assessment system they first used was different [64]. The test at Aalto University was implemented by STACK computer aided assessment system. STACK allows teachers to construct personalized mathematics exercise assignments. In personalized questions the parameters are randomized [24, 74].

The test included 16 questions that measured procedural knowledge [31]. The questions were graded by 1 or 0 points and students were able to try each question three times. Topics of the questions were derivative, logarithm and exponential function, inequalities, integrals, manipulation of algebraic expressions, arithmetic, trigonometry and equations. To see the exact names of the questions, see Table 5.1. The test was established by a university mathematics lecturer who noticed that the skills of some incoming engineering students are inadequate. Thus topics were chosen so that they would cover the most typical exercises in upper secondary school advanced mathematics curriculum. Another important factor was that they were able to be implemented by computer and to be randomized [81].

Because the test questions are randomized, the same test can be used year after year. This makes it easier to compare the results of different years with each other. Thus the questions of the test cannot be published. An example of the Derivative 1 -question of the test is below.

Let the function

$$f(x) = x \cdot (\sin(x) + \cos(x))$$

be given. Calculate the derivative of this function.

Table 5.1: Topics of the questions in Basic Skills Test of Mathematics.

Topics of the Questions	**Number of questions**
Derivative	2
Equation	2
Exponential	1
Inequality	2
Integral	2
Logarithm	1
Numbers	2
Trigonometry	2
Total	16

5.2 Index of Learning Styles Questionnaire

In the autumns of 2009 and 2010 the learning styles questionnaire was sent to all new engineering students. Answering the questionnaire was voluntary. The questionnaire was a Finnish translation of Felder and Soloman's Index of Learning Styles Questionnaire (ILS) [79]. Because there are some Swedish speaking students at Aalto University, the questions were also translated into Swedish. International students had an opportunity to answer the original questionnaire [79]. The questionnaire includes 44 questions among four learning style dimensions (see Appendices A, B and C).

This instrument was chosen because it has been widely used in engineering education. Its reliability and validity has been measured by Zywno [86]. According to him, there was a moderate reliability of all dimensions. However, some overlap between the dimensions Sensing-Intuitive and Sequential-Global has been found [83]. Zywno discovered that ILS is a suitable tool to assess the learning of engineering students [86]. The questions were exactly the same as Jorma Vainionpää used in his study. He studied the learning styles of communication science students in the Finnish Virtual University (see chapter Theoretical framework and [82]).

Chapter 6

Results

6.1 Basic Skills Test of Mathematics

The mean score of the Basic Skills Test of Mathematics was 9.26 in 2008 (SD=3.84, N=889), 9.35 in 2009 (SD=3.72, N=843), 9.84 in 2010 (SD=3.72, N=833) and 10.03 in 2011 (SD=3.56, N=784). The distributions of the points students received from the test each year are presented in Figure 6.1. Distributions are not Gaussian: quite a few students received 15 or 16 points from the test. There are degree programs that draw mathematically highly skilled students nationwide. These students tend to get better results from the Basic Skills Test, which might skew the distributions. At Tampere University of Technology the distribution has been more like Gaussian [30]. About 15 % of the students at Aalto University have received five points or less from the test, whereas in TUT in 2004 the rate was 20 % [64].

The most difficult topics in the Basic Skills Test were related to symbolic fractions, logarithms and trigonometric expressions (see Figure 6.2). These topics tend to be difficult also in upper secondary school mathematics. The logarithm question was different from the routine exercise in upper secondary school. It also required students to remember some calculation rules of logarithm. In the light of the results, logarithm topics should be taught more thoroughly in upper secondary school as logarithm is applied extensively in engineering studies. Trigonometrical exercises demanded a deeper understanding than other exercises. Topics of the easy questions were quotient of factors, linear equations and inequalities. These questions were very routine ones and, on the other hand, the topics were taught already on secondary school.

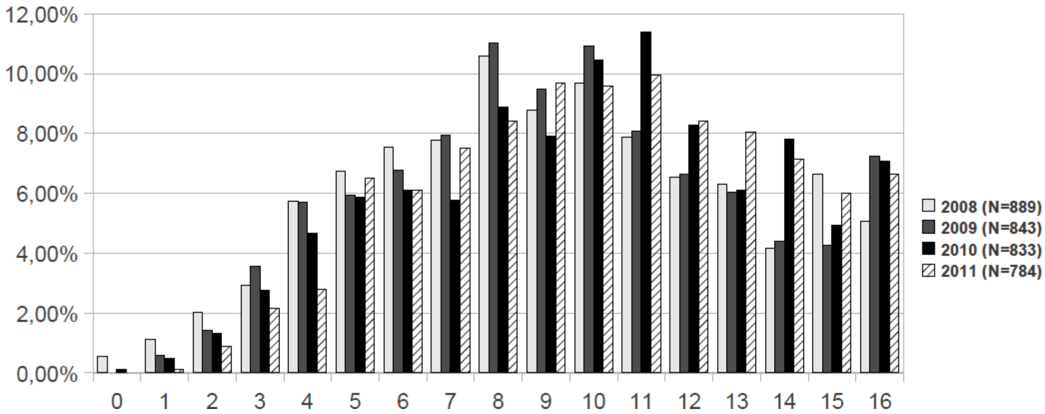

Figure 6.1: Distribution of the results of the Basic Skills Test of Mathematics in the years 2008-2011.

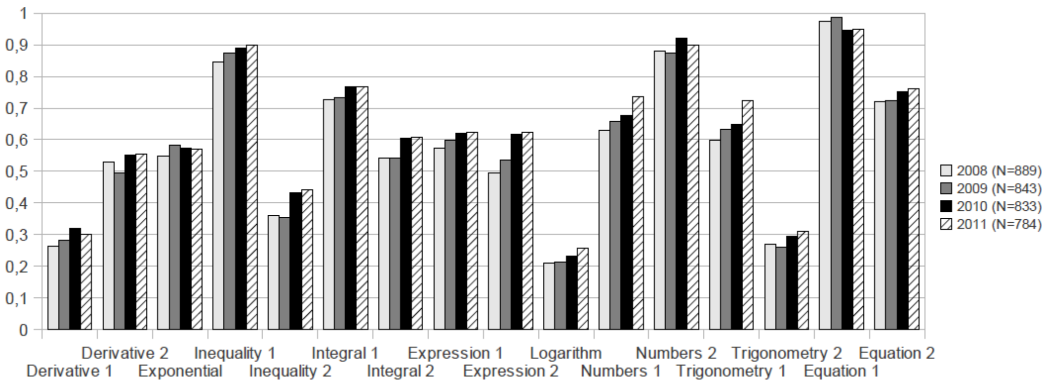

Figure 6.2: Distribution of the points of each exercise of the Basic Skills Test of Mathematics in the years 2008-2011. The length of the pillar describes average marks from the problem assignment (the maximum is 1).

The average score of the test has increased significantly during the years 2008-2011 (see Table 6.1). The reason for this might be the technical unawareness of the first year. The amount of student admission has also decreased. The average score of the Basic Skills Test at Tampere University of Technology has increased

Table 6.1: The results of t-test comparison with Bonferroni correction [59] of averages scores in 2008-2011. The number 1 indicates that there is a significant difference between average scores, the number 0 that there is no significant difference. p indicates the significance level.

Year	2009	2010	2011
2008	0 (p=0.3266)	1 (p=0.0001)	1 (p=0.0000)
2009		1 (p=0.0056)	1 (p=0.0001)
2010			0 (p=0.1981)

slightly over these years as well [63], but the increase has not been as notable as at Aalto University. At Aalto University, there was also a significant difference (p=0.0000) in 2011 between the results of those students who have had gap years after their upper secondary school studies (average score 9.18) and students who begun their studies straight after upper secondary school (average score 10.68).

6.1.1 Reliability and validity of the test

Reliability is defined as repeatability of the instrument [57]. According to Wolf [15, 84], there are four main factors that might affect reliability in tests: the range of the group, the group's level of proficiency, the length of the measure, and the way in which reliability is calculated. In this study, nearly all new engineering students (besides architecture students) at Aalto University answered the Basic Skills Test during their first study year, so the answer rate was very high. The sample also represents well the common level of proficiency, which can be seen also by comparing the results of Aalto University students with the results of students at Tampere University of Technology.

There were 16 questions in the test, and students had one hour time to answer it, so the length of the test was appropriate. However, for some students the answer time might have been too short, especially if they had some technical problems. With the resources we have at the moment, it is not possible to lengthen the test time. The test was available in Finnish and Swedish, so no language problems should have existed. Also an English version was available.

The difficulty level of the test assignments varied: there were couple of very easy, and also a couple of more complex exercises in the test. Everyone who has studied advanced mathematics in upper secondary school should theoretically have been able to solve all the assignments. Thus the difficulty level of the test was appropriate. By computer aided assessment the grading of the assignments is totally objective. Also the sample size was very large (over 700 students per year). In this research students were tested only once, so no comparisons between results in different times can be made.

The content validity of the Basic Skills Test was examined by using the proposed use of time -schedule of the upper secondary school mathematics book series ”Pitkä Matematiikka” (see [34] and other books of that series). The book includes a list of topics presented in the book and a proposed amount of hours for teaching each topic. With this list, it can be estimated which topics are important in a particular course. The coverage of the topics were calculated by comparing whether the topic is covered in the Basic Skills Test or not. The number of lessons of the topics covered in the Basics Skills Test were compared to the total number of lessons in the course (see Table 6.2). The topics were also compared to official upper secondary school advanced mathematics curriculum [62], and the results of this analysis showed that 47.2 % of the topics in the curriculum were in the Basic Skills Test.

The results of the book analysis show that the questions in the Basic Skills Test are mostly based on the topics of upper secondary school advanced mathematics courses 1,2,3,7,8,9 and 10. Geometrical exercises are difficult to be implemented by computer which might be the reason for the lack of geometric assignments in the test. On the other hand there were assignments concerning trigonometry in the test.

The lack of vector exercises in the test is unfortunate. If a new version of the test will be generated in the future, there should be some vector assignments too. Vector calculus is an important topic in most of the basic mathematics courses at Aalto University. Probability and statistics are taught in a separate compulsory course. These topics are not taught in basic mathematics courses at Aalto University, which might be the reason for the lack of those assignments in the Basic Skills Test.

On the other hand, the topics that are well covered in the Basic Skills Test are also important in basic mathematics courses at Aalto University. For example calculus is an important topic in these courses. The contents in the courses 1,2,7,8,9 and 10 (see Table 6.2) are those that students supposed to have as preliminary knowledge about calculus before entering to Aalto University.

Table 6.2: The coverage of the obligatory courses of Finnish upper secondary school advanced mathematics curriculum in the Basic Skills Test (BST)

Course	**Coverage in BST**
1. Functions and equations	75 %
2. Polynomial functions	71 %
3. Geometry	18 %
4. Analytic geometry	0 %
5. Vectors	0 %
6. Probability and statistics	0 %
7. Differential calculus	50 %
8. Root and logarithm functions	61 %
9. Trigonometrical functions and sequences of numbers	40 %
10. Integral calculus	29 %
Average	34 %

6.2 Experiences of continuous assessment

At Aalto University, automatic assessment system STACK [74, 73] has been used in teaching since 2006. In this thesis, the results of two studies are reported. For more information about earlier studies, see [8, 65, 71] and the chapter Theoretical framework of this thesis.

6.2.1 Experiences from the course S1

Basic course in mathematics S1 is a compulsory course for electrical and telecommunications engineering students. Contents of the course are complex numbers, matrix algebra, linear systems of equations, eigenvalues, differential and integral calculus for functions of one variable, introductory differential equations, and Laplace transforms. STACK has been implemented on the course since 2007, and the same problems have been used in the course thereafter. However, the perceived mistakes have been fixed. In addition to the STACK exercises, the course consists of lectures, traditional exercise sessions supervised by an instructor and three exams. Students can also choose to participate only in the exams.

Statistical analysis of the course results (see Table 6.3) shows that there is a significant ($p \leq 0.0002$) correlation between the amount of students' exercise activity and the scores from the exams. The number of problems students tried to solve explains the success in examination better than the results of the Basic Skills Test. This result supports the belief that mathematics is mostly learned by practising with many problems. The general training activity of failing students is low, whereas students with high grades also train more (see Table 6.4). The actual effects of STACK to the learning outcomes is difficult to be assessed. However, some certain improvements in students' skills have been observed. Ruutu's independent study showed a significant increase in the proportion of new students in telecommunications engineering who pass a basic course in mathematics in their first study year after e-assessment was introduced [72].

Table 6.3: Spearman's rank correlation between the Basic Skills Test, the exercise and the exams scores on the course S1 in the years 2007-2009.

Year	Basic skills	Traditional	STACK
2007	n/a	0.49	0.57
2008	0.45	0.67	0.71
2009	0.35	0.69	0.66

Table 6.4: The percentage of automatically assessed (above) and traditional (below) exercise assignments solved by students. Numbers are sorted by the grade given (0-5), where 0 means failing the course.

Year	0	1	2	3	4	5
2007	11.6 %	18.0 %	33.0 %	31.2 %	64.0 %	79.7 %
	3.78 %	7.77 %	20.2 %	9.40 %	26.8 %	61.6 %
2008	13.2 %	23.6 %	36.6 %	49.6 %	65.6 %	75.0 %
	4.79 %	13.6 %	16.2 %	28.9 %	56.8 %	58.4 %
2009	14.6 %	23.3 %	38.8 %	49.5 %	51.2 %	78.3 %
	3.77 %	10.0 %	29.2 %	50.5 %	68.2 %	92.5 %

6.2.2 Continuous assessment in the course Discrete Mathematics

Encouraged by previous good experiences about automatic assessment, an experimental course Discrete Mathematics was set up in 2010 (see also [9, 53]). The exercise assignments formed a significant portion of the final grade (see Figure 6.3). Student could even pass the course without taking the exam. This approach follows continuous assessment model [7]. This model is difficult to be implemented effectively on a large course because of often resulting plagiarism. The use of STACK exercises reduced the possibility of cheating in this course. Classroom lectures and face-to-face exercise sessions were held alongside the extensive use of e-assessment.

Scores from the exams and exercise assignment are illustrated in Figure 6.4. Grading system seems to be highly motivating for students. The Spearman's rank correlation between exam scores and traditional scores is 0.69 and between exam

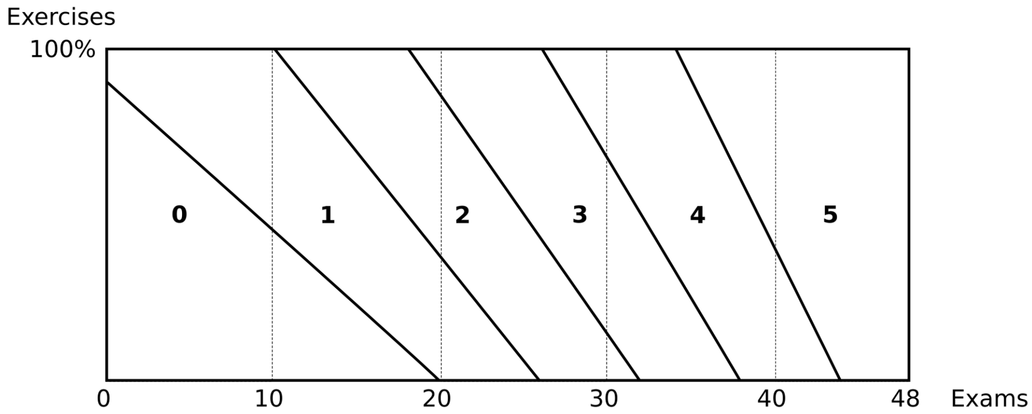

Figure 6.3: The grading system on the course Discrete mathematics: proportion of exercises solved is on the y-axis and exam score (0-48 points) is on the x-axis. The grades are 0 (fail) and 1-5, where 1 is the least passing grade and 5 is the best.

scores and scores from STACK exercises 0.73. However, there are some students who could solve problems with e-assessment system but could not solve a very similar one in the exam. Because of the randomization of the STACK exercises, students were likely to solve the assignments by themselves. A possible explanation for a failure could be stress in the exam situation, but this question requires further investigation. After the course, feedback was collected from the students. More information about the results of the questionnaire is in [53, 54].

6.3 Learning styles

The learning styles questionnaire was sent by e-mail in the autumn of 2009 to 843 students who begun their studies in the same year. The number of valid responses was 203 (24 %). In the autumn of 2010 the questionnaire was sent to 833 students and the number of valid responses was 431 (52 %). The answer rate in 2010 was higher probably because of earlier sending time and a reminder e-mail. The $r \times c$ Test for Homogeneity [59] was used to test the homogeneity of the two samples. Results of the test showed that results of the Active/Reflective, Sensing/Intuitive and Visual/Verbal dimensions were homogeneous in the years 2009 and 2010. However, in the Sequential/Global dimension results were not homoge-

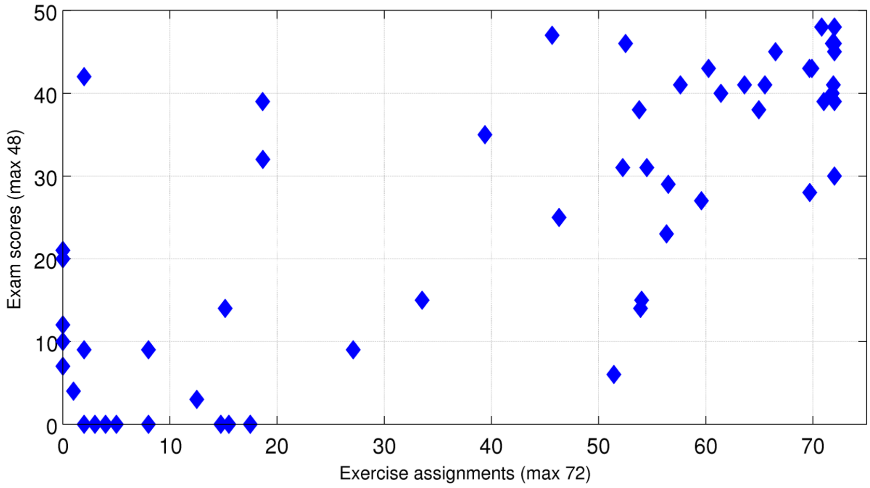

Figure 6.4: Student scores from exams and exercises by the time of the mid-term examination.

neous. Thus, despite the difference of the answer rates, the results are quite well in line.

In each four dimensions of the learning styles questionnaire there were 11 questions. From each question student could get 1 or -1 points (or zero if not answered). In this chapter, two kinds of distributions are showed. First, the distributions of the points in each dimension are considered. Second, the results of each dimension are divided into five categories 1-5. For example in Visual/Verbal dimension one point means strongly verbal, three points balanced and five points strongly visual. The same kind of categorization was used in Jorma Vainionpää's study [82].

6.3.1 Active/Reflective dimension

The mean value of the results of the Active/Reflective dimension in 2010 (see Table 6.5) is 0.39 and standard deviation 4.42. When dividing the results into five categories (see Table 6.6), it is seen that most of the engineering students (60.3 %) at Aalto University are in the middle of the dimension. Thus it seems that engineering students feel themselves comfortable in classes that include both active work and reflective work. Communication science students in the Finnish Virtual University were more active learners than the students at Aalto University [82].

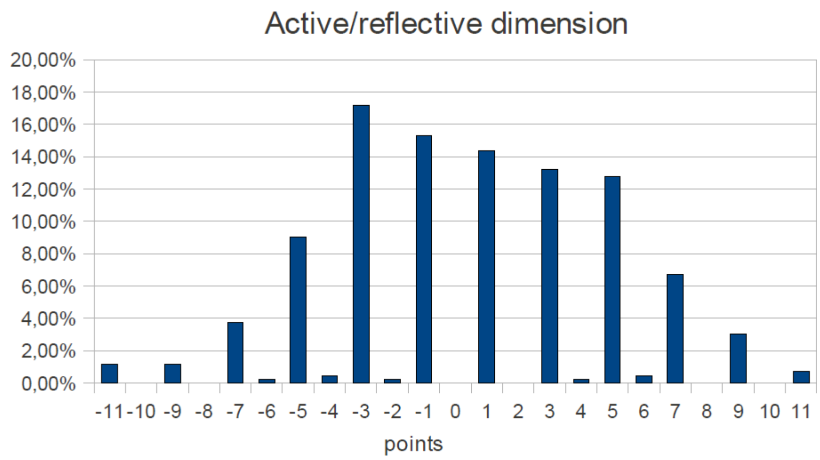

Figure 6.5: Distribution of the points of the Active/Reflective dimension in learning styles questionnaire in 2010.

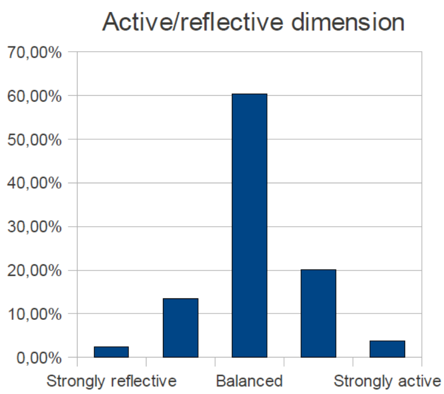

Figure 6.6: Distribution of the points of the Active/Reflective dimension in learning styles questionnaire divided into five categories in 2010.

6.3.2 Sensing/Intuitive dimension

The mean value of the results of the Sensing/Intuitive dimension in 2010 (see Table 6.7) is 4.4 and standard deviation 4.53. When dividing the results into five categories (see Table 6.8), it is seen that most of the engineering students (total 69.6 %) at Aalto University are either in the middle of the dimension or moderate sensing learners. Also 24.6 % of the students are strongly sensing learners. However, most of the engineering courses favor intuitive learners. Thus mathematics teaching should include, for example, more concrete teaching material. Also, communication science students tend to be more sensing learners [82].

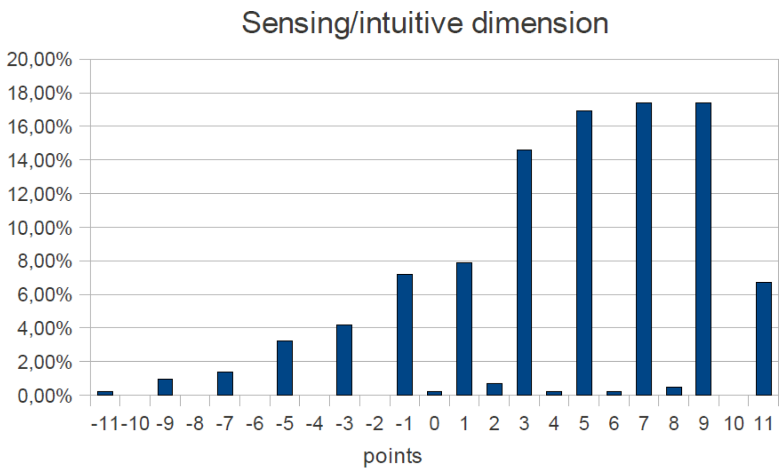

Figure 6.7: Distribution of the points of the Sensing/Intuitive dimension in learning styles questionnaire in 2010.

6.3.3 Visual/Verbal dimension

In the Visual/Verbal dimension the mean value of the results is 4.21 and standard deviation 4.16 (see Table 6.9). Table 6.10 shows that most of the engineering students (total 79.6 %) are either in the middle of the dimension or moderate visual learners. 20.0 % of the students are strongly visual learners. This result

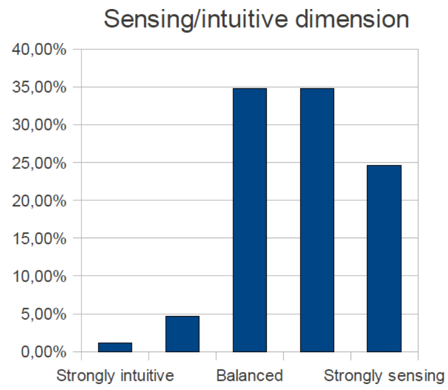

Figure 6.8: Distribution of the points of the Sensing/Intuitive dimension in learning styles questionnaire divided into five categories in 2010.

is in line with earlier studies (for example [5, 21]) and the results of the study of communication science students [82].

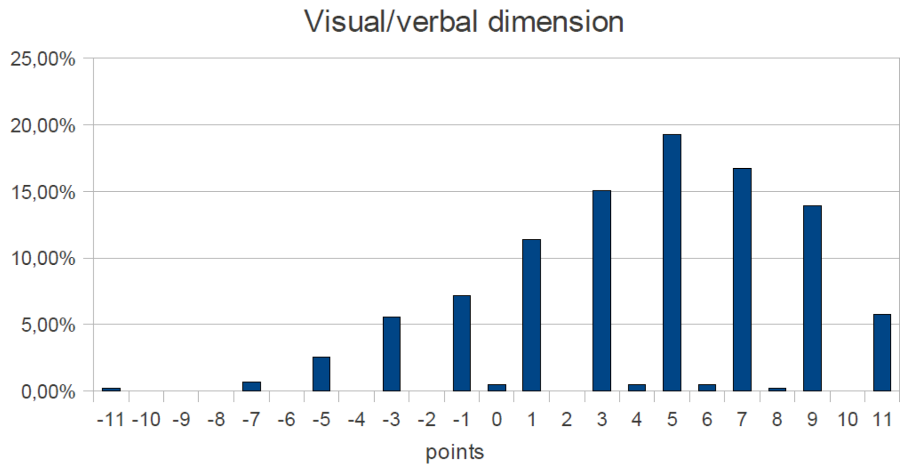

Figure 6.9: Distribution of the points of the Visual/Verbal dimension in learning styles questionnaire in 2010.

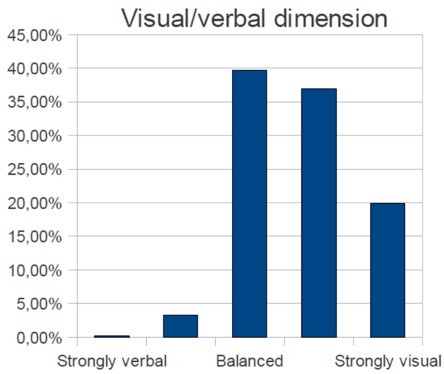

Figure 6.10: Distribution of the points of the Visual/Verbal dimension in learning styles questionnaire divided into five categories in 2010.

6.3.4 Sequential/Global dimension

The mean value of the results in the Sequential/Global dimension is 1.61 and standard deviation 4.27 (see Table 6.11). Table 6.12 shows that most of the engineering students (59.9 %) are in the middle of the dimension. However, there are more sequential than global learners. According to Vainionpää's study [82], communication science students tend to be more global learners than engineering students. A reason for this might be the differences between the natures of these topics: engineering topics are perceived to be more sequential than humanities.

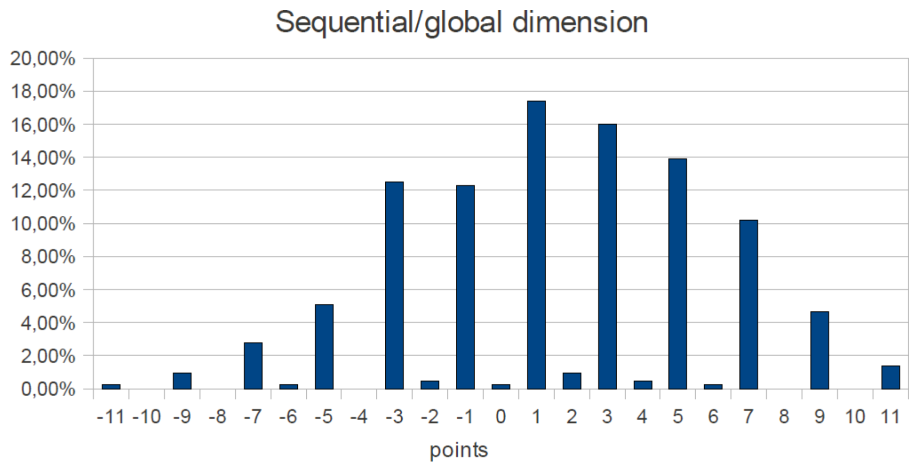

Figure 6.11: Distribution of the points of the Sequential/Global dimension in learning styles questionnaire in 2010.

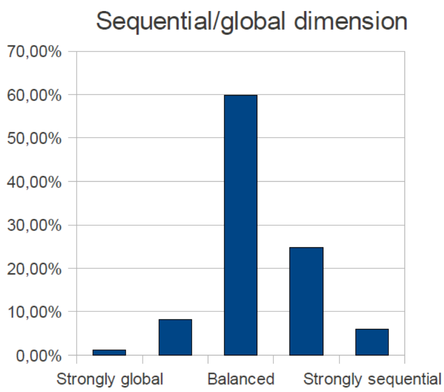

Figure 6.12: Distribution of the points of the Sequential/Global dimension in learning styles questionnaire divided into five categories in 2010.

6.4 Summary of the results: the impacts of different factors

A basis for a good teaching method would probably be that the student learns despite his/her learning style. Thus a statistical analysis was made for all the first basic mathematics courses in 2010 in order to find out the impacts of different factors (exercise activity, results of the Basic Skills Test and learning styles) to the exam results. The relationship was studied in each first semester mathematics course separately because of the difference in assessment methods and difficulty levels of the courses. A multivariate regression analysis [48, 59] was made to study the possible joint impacts of the factors.

First it was examined if there was a positive linear relationship between the results of the exam scores and the exercise points. Results showed that there was a statistically significant ($p = 0.0000$) positive linear relationship in all courses, which is obvious. This result is in line with the results of the study presented in the section Experiences from the course S1. The R^2 values of the exercise points to the exam scores were also good (see Table 6.5). There was no remarkable difference between the R^2 values of the courses where automatic assessment system STACK was used (C1, K1, S1) and courses which included only traditional exercises (L1, P1). The advanced mathematics course L1 is more difficult than other courses, which might explain the higher significance of the exercise scores to the course results.

The linear relationship between the results of the Basic Skills Test and the exam scores was also statistically significant ($p \leq 0.006$ in all courses) and positive but not as strong as the relationship between the exam scores and the exercise points. Also, when examining students who got four points or less from the Basic Skills Test (BST) in 2009 and attended the basic course of mathematics (N=64, 10 %), it is seen that this group fared weakly in basic courses (see Table 6.6).

No relationship was found between different learning styles and the exam results after adjusting the effects of the factors of the exercise scores and the results of the Basic Skills Test. Thus the learning style a student has seems not to strongly affect the learning outcomes. On the other hand, there might be a connection between learning styles and exercise activity but the sample size is perhaps too small to

Table 6.5: The R^2 values of exercise points and results of the Basic Skills Test (BST) to exam scores in 2010.

Course	R^2 **value**	
	Exercise scores	Exercises scores and results of the BST
C1	47 %	54 %
K1	38 %	45 %
P1	45 %	49 %
S1	44 %	52 %
L1	54 %	60 %

Table 6.6: Cross tabulation of the course grade and points from the Basic Skills Test (BST) in 2009.

	Course grade						**Total**
BST points	0	1	2	3	4	5	
≤ 4 points	13 20.3 %	12 18.8 %	16 25.0 %	11 17.2 %	7 10.9 %	5 7.8 %	64 100 %
> 4 points	81 13.9 %	59 10.2 %	96 16.5 %	114 19.6 %	113 19.5 %	118 20.3 %	581 100 %
Total	94 14.6 %	71 11.0 %	112 17.4 %	125 19.4 %	120 18.5 %	123 19.0 %	645 100 %

detect this phenomenon.

Chapter 7

Discussion

Students come to university from different backgrounds. Some of them come straight from upper secondary school with good knowledge of mathematics. Others might have come to university to study their second degree or they have had gap years for some other reason. It is natural that these students' preliminary knowledge might be different and they might also be used to different teaching methods. The results of the Basic Skills Test and Index of Learning Styles Questionnaire give teachers valuable knowledge of students' learning prerequisites.

The results of the Basic Skills Test show that some students have many gaps in their knowledge of mathematics at the beginning of their university studies. On the other hand, students in the most popular degree programs tend to get very good results from the test. There are several basic mathematics courses at Aalto University with different contents. Teachers of these courses are able to use the results of this test when planning their teaching. However, the correlation between the results of the Basic Skills Test and first year mathematics courses was only moderate. One reason for this might be the different level of difficulty in the courses and thus more analysis should be made in the future.

The increase of the average score of the test during the investigated time period is significant. This result is not in line with international studies [29, 47]. In this study, the reasons for the increase were not studied. However, possible reasons for the increase might be the decrease of the student intake and the development of upper secondary school mathematics teaching. Also, the popularity of re-formed Aalto University has increased during these years.

Students who have had gap years before their studies tend to have weaker results from the test than students who come to university straight from upper secondary school. At Tampere University of Technology it has been noticed that the more gap years students had, the weaker their success was in the Basic Skills Test. The students who fared weakly in the test were instructed to attend obligatory remedial instruction of upper secondary school mathematics topics [30, 64]. At Aalto University, some web-based remedial material have also been developed [43], but the use of it is voluntary at the moment.

Since the success in the Basic Skills Test does not ensure the success in basic mathematics courses, other factors that might influence success were also discovered. E-assessment can increase flexibility, and thus improve the quality of teaching. Besides diagnostic testing, it also provides opportunities for improved feedback for students. By using STACK exercises as a part of assessment, it is possible to increase the weighting of exercises in course grading. This can be highly motivating especially for students who tend to underachieve in exam situations. It also encourages students to work during the whole course, not only before the exam. According to the results of this study, the more students solve exercises during the course, the better grades they get [69].

One future challenge might be the increased use of symbolic calculators in upper secondary school mathematics. Since the year 2012, symbolic calculators have been permissible in matriculation examination in Finland [36]. Thus students are more familiar with CAS programs than before. This makes the use of STACK more easier for students. On the other hand, exercises have to be evaluated so that the system does not just check if the answer is complete but also requires some intermediate stages.

The flexibility of mathematics courses can also be increased by taking into account different learning styles in teaching. According to earlier studies, engineering students are active, sensing, visual and sequential learners [10, 21, 85]. Results of the study of Aalto University students showed that engineering students tend to be sensing and visual learners. Results in other dimensions were more balanced [27]. A reason for the difference between Finnish students and other students could be that in Finland more subjects are classified as engineering subjects. There are also some differences between the learning styles of engineering students and communication science students. A reason for that might be the difference of the nature of these subjects.

The mismatches between the learning styles of engineering students and traditional teaching styles [21] should be fixed. Because most of the engineering students at Aalto University are visual learners [27], teachers should use more visual elements, for example figures, in their teaching. New technical teaching aids, for example GeoGebra [1], enables teachers to demonstrate visual representations of mathematical tasks in their lectures. Also with automatic assessment system STACK, it is possible to evaluate graphical exercises for students.

Sensing learners might like some "learning by doing" exercises. Some work for this direction has already been done. There have been teaching experiments at Aalto University whose targets have been to activate students in the classroom [28]. These kinds of teaching methods are suitable both for active and sensing learners. In traditional engineering mathematics lectures, most of the materials are presented in logically ordered progression. Sequential learners feel comfortable with this kind of teaching method. For helping global learners, the instructor should provide a big goal for the lesson before presenting one step at a time.

Although the teaching methods in the mathematics courses of Aalto University are still quite traditional, some improvements have already been made. The ongoing reform of bachelor level studies at Aalto University impacts the practices of mathematics courses as well. Besides the contents of the course, the teaching methods are also under reconsideration. If the amount of lectures and exercises are going to be decreased, the importance of self study materials, for example STACK exercises, will increase.

There are also many other factors that have important implications for learning, for example level of motivation, approaches to learning and mathematics anxiety [19, 20, 49]. These factors require further studies.

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Articles

This chapter includes articles:

Havola, Linda: New engineering students' learning styles and basic skills in mathematics. In Silfverberg, H. & Joutsenlahti, J. (eds.) *Tutkimus suuntaamassa 2010-luvun matemaattisten aineiden opetusta. Matematiikan ja luonnontieteiden opetuksen tutkimuksen päivät Tampereella 14.-15.10.2010.*, 117-130, 2011.

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New engineering students' learning styles and basic skills in mathematics

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In Aalto University mathematics teaching has been an active field of development in the past few years. The motivation has been to increase the number of students passing compulsory mathematics courses. In this study the learning styles and basic skills as background information were considered to better understand students' learning processes. Learning styles of engineering students were studied by using Felder and Soloman's Index of Learning Styles Questionnaire. All new students took also the Basic Skills Test of mathematics in the autumns 2008–2010. According to the results students have many gaps in mathematics for example when working with symbolic fractions, logarithms and trigonometric expressions. Results of the learning styles questionnaire showed that most of the engineering students in Aalto University tend to be visual and sensing learners whereas in the active/reflective and sequential/global scales results were evenly distributed. Results were compared to earlier studies. No strong correlation was found between the results of the Basic Skills Test and learning styles. Results of this study are useful when developing teaching methods and mathematics curriculum.

Keywords: engineering mathematics, engineering education, Basic Skills Test, learning styles

Introduction

In Aalto University School of Science (former Helsinki University of Technology) mathematics teaching has been an active field of development in the past few years (for example Rasila, Havola, Majander & Malinen 2010; Rasila, Harjula & Zenger 2007). The motivation has been to increase the number of students passing compulsory engineering mathematics courses. Problems are, for example, first year students' varying level

H. Silfverberg & J. Joutsenlahti (toim.) 2011.
Tutkimus suuntaamassa 2010-luvun matemaattisten aineiden opetusta. Matematiikan ja luonnontieteiden opetuksen tutkimuksen päivät Tampereella 14.–15.10.2010.
Tampere: Tampereen yliopisto, Kasvatustieteiden yksikkö, 118–131.

of skills in mathematics and passivity in studying (Rantanen & Liski 2009). Aalto University has been looking for solutions to these problems by actions that support and activate students and increase flexibility. Equally important project has been to gather data to gain understanding of the underlying reasons of problems in order to better address teaching.

The aim of this research is to find reasons, why students do not pass the basic courses in mathematics, and to find out if the actions taken to the date work as intended. By using statistical analysis it is studied, how do the results of the Basic Skills Test of mathematics compare to the results of the first year mathematics studies. Other things that contribute to failure, and their significance, will be also considered. Possible reasons can be for example inappropriate teaching and learning styles, unfamiliarity of the methodology required in university studying and social reasons.

The research questions are:

1. What are the starting skills in mathematics of new engineering students according to the Basic Skills Test?
2. What learning styles do new engineering students have?

Learning styles

Learning styles in higher education have been studied for example in (Havola 2010; Alaoutinen, Heikkinen & Porras 2010; Zywno 2003). Cassidy (2004) made a meta-analysis of different learning style theories and models. According to him many or all the learning style theories he proposed were valid. Different theories will simply offer approaches with different emphases for investigation (Cassidy 2004).

Learning styles are the ways in which individuals characteristically approach different learning tasks (Hartley 1998). There have been many different learning styles models in the literature (for example Kolb & Kolb 2005). One of the most common models among engineering education is Felder-Silverman Learning Styles Model (FSLSM) that is used in this research (Felder & Silverman 1988). The Index of Learning Styles Questionnaire (ILS) (Felder & Soloman 2001) was used also in Jorma Vainionpää's study (Vainionpää 2006). He studied learning styles of communication science students in a web-based course in Tampere University. In Aalto University there are also some web-based elements, for example automatically assessed STACK-exercises (Harjula 2008) in mathematics courses. By using the same questionnaire it is possible to compare the results to each other.

The Index of Learning Styles Questionnaire includes 44 questions from four different learning style dimensions. The learning styles dimensions Felder and Silverman proposed are neither original nor comprehensive. All four dimensions are combinations of the results of earlier studies and models. In the initial model Felder and Silverman described five different learning style dimensions: sensing-intuitive, visual-auditory, inductive-deductive, active-reflective and sequential-global. After some reconsiderations the inductive-deductive dimension has been omitted and the name auditory has been changed to the name verbal (Felder & Silverman 1988).

Sensing and intuition are two different ways people perceive the world. Sensing learners observe and gather data through the senses whereas intuitive learners perceive indirect by way of the unconscious – speculation, imagination and hunches. Most of the people tend to favor one or the other way but everyone uses both faculties. Most engineering mathematics courses emphasize concepts rather than facts and thus favor intuitive learners whereas majority of the engineering students are sensing learners. They may not perform as well at school as intuitive learners but both are needed as engineers (Felder & Silverman 1988).

Another dimension of the ILS model is visual and verbal (initially auditory) (Felder & Silverman 1988). Visual learners remember best what they see and verbal learners what they hear (and then say). Most of the people in the college age are visual learners (Barbe & Milone 1981). Most of the engineering mathematics teaching is verbal (lecturing) or visual presentation of verbal information (mathematical symbols).

Teaching may sometimes also be too passive which is not ideal situation for active learners. They work well in groups whereas reflective learners work better by themselves or with at most one other person. In addition, reflective learners do not either learn much in situations which do not enable them to think about information being presented. Both are needed as engineers: reflective learners are the theoreticians, mathematical modelers and active learners are the organizers and decision makers (Felder & Silverman 1988).

Most of the engineering education involves the presentation of material in logically ordered progression. Sequential learners are comfortable with this system because they master the material more or less as it is presented. However global learners cannot learn in this way. Instead they learn in fits and starts. The instructor should provide a big picture or goal of the lesson to global learners before presenting one step at a time (Felder & Silverman 1988).

Zywno measured the reliability and validity of the Index of Learning Styles Questionnaire by using pretest-post test method (Zywno 2003). There was a moderate reliability of all scales. However some overlap between Sensing-Intuitive and Sequential-Global scales has been found (van Zwanenberg & Wilkinson 2000). Zywno found out that ILS is a suitable tool to assess the learning of engineering students (Zywno 2003). However further evaluations are still needed.

Diagnostic testing of freshmen students in literature

Diagnostic testing in mathematics has also been widely used in higher education since 1990s (Lawson 2003; Batchelor 2004). Coventry University started systematic diagnostic testing in mathematics in 1991 and the test has remained the same over the whole period until 2001. The test consists of multiple-choice questions and it is taken during the introduction week. Results of the tests have showed that entry skills of new students have declined over time (Lawson 2003).

Also in mathematics departments of Dutch universities mathematical abilities of incoming students have dropped significantly in recent years (Heck & van Gastel 2006). Freshmen students had many problems in making the transition from school to university mathematics. On their second day at university freshmen students at the Faculty of Science took a one-hour diagnostic test in mathematics. The test was implemented by automatic assessment system Maple T.A. However students were able to hand the answers on a scrap paper. In the fifth week of the studies, students took the second diagnostic test. This test was taken in digital format only. By pretest-post test design, teachers and students can see the progress made in the meantime during the basic mathematics practice sessions. Those who did not pass the tests were guided to the remedial teaching of mathematics (Heck & van Gastel 2006).

Analysis of the Dutch students' results of the test showed that students make computational mistakes even on simple calculations with fractions. A great variety of misconceptions were noticed in algebraic manipulations. Students in Dutch universities appreciated that they were told the mathematics abilities desired by the universities and were informed about their own level (Heck & van Gastel 2006).

Methods

Basic Skills Test of mathematics

All new engineering students of Aalto University took the Basic Skills Test of mathematics in autumns 2008–2010. The test was a part of a compulsory course for all but architecture students, so nearly all students took the test. Students in architecture do not have to take basic courses in engineering mathematics. During the test there was an instructor in the class who answered technical questions.

The test problems were originally created in Tampere University of Technology (TUT) but the original assessment system used there was different because of software license issues (Pohjolainen, Raassina, Silius, Huikkola & Turunen 2006). The test in Aalto University was implemented by STACK (System of Teaching and Assessment using Computer algebra Kernel) computer aided assessment system. STACK is a system that allows teachers to construct personalized mathematics exercise assignments for students. Personalized questions are based on technique where parameters are randomized (Harjula 2008; Sangwin 2004; 2007).

The test included 16 questions that were graded by 1 or 0 points. Students were able to try each question three times. Topics were derivative, logarithm and exponential function, inequalities, integrals, manipulation of algebraic expressions, arithmetic, trigonometry and equations (see Table 1). The test was established by a university mathematics lecturer. Topics were chosen so that they would cover the most typical exercises in high school advanced mathematics curriculum. They were also possible to be implemented by computer and to be randomized (E. Turunen, personal communication, March 30, 2011). An example of the derivative question of the test is in Figure 1. Although problems were randomized they were created so that the difficulty level did not vary significantly between different instances. Technique also enables universities to use the same test year after year. This makes it easier to compare the results of different years with each other.

TABLE 1. Topics of the questions in Basic Skills Test of Mathematics.

Topics of the questions	Amount of questions
Derivative	2
Equation	2
Exponential	1
Expression	2
Inequality	2
Integral	2
Logarithm	1
Numbers	2
Trigonometry	2
Total	16

Let the function

$$f(x) = x \cdot (\sin(x) + \cos(x))$$

be given. Calculate the derivative of this function.

Remark. Power expressions are given in the form a*x^n, for example 3*x^(1/5). Sine and cosine expressions are given in the form sin() and cos (), for example sin(2*x).

$f'(x) =$ [ ]

FIGURE 1. An example of the question Derivative 1 of the Basic Skills Test of mathematics.

Learning styles questionnaire

In autumns 2009 and 2010 the learning style questionnaire was sent to all students who participated the Basic Skills Test. The questions were in Finnish and they were exactly the same as Jorma Vainionpää (2006) used in his study. The questions have also been translated into English and Swedish. All 44 questions were statements that had two answer options. For more information about the questionnaire, see (Felder & Soloman 2001). Some examples of the questions (in English) are in Figure 2.

In each four dimensions of the learning styles questionnaire, there were 11 questions. The results of each dimension were divided into five categories 1–5. Category 1 means one point etc. For example in visual/verbal scale one point means strongly verbal, three points balanced and five points strongly visual. Same kind of categorization was used in Jorma Vainionpää's study (2006).

1. I understand something better after I
   - o **(a)** try it out.
   - o **(b)** think it through.
2. I would rather be considered
   - o **(a)** realistic.
   - o **(b)** innovative.
3. When I think about what I did yesterday, I am most likely to get
   - o **(a)** a picture.
   - o **(b)** words.
4. I tend to
   - o **(a)** understand details of a subject but may be fuzzy about its overall structure.
   - o **(b)** understand the overall structure but may be fuzzy about details.

FIGURE 2. Some examples of the questions in Felder and Soloman's Learning Styles Questionnaire (2001).

Results

Results of the Basic Skills Test of mathematics

The mean score of the Basic Skills Test was 9.26 in 2008 (N=889), 9.35 in 2009 (N=843) and 9.84 in 2010 (N=833). In Figure 3 you can see the distributions of the points students got from the test in each year. The distributions are not Gaussian: there are quite many students who have got 15 or 16 points from the test. In Tampere University of Technology (TUT) the distribution has been more like Gaussian distribution (Huikkola, Silius & Pohjolainen 2008). Also about 15% of the Aalto University students in 2010 have got five points or less from the test whereas in TUT in 2004 the rate was 20% (Pohjolainen et al. 2006).

The questions in the Basic Skills Test that proved to be the most difficult were related to symbolic fractions, logarithms and trigonometric expressions. However there were also some questions that were very easy.

Topics of the easy problems were quotient of factors, linear equations and inequalities (see Figure 4).

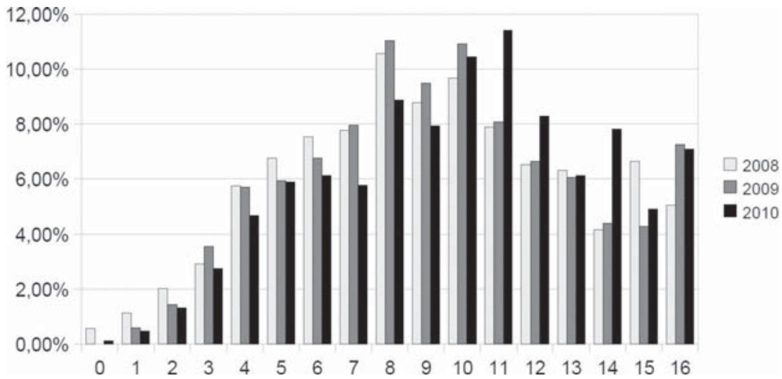

FIGURE 3. Distribution of the results of the Basic Skills Test of mathematics in years 2008–2010.

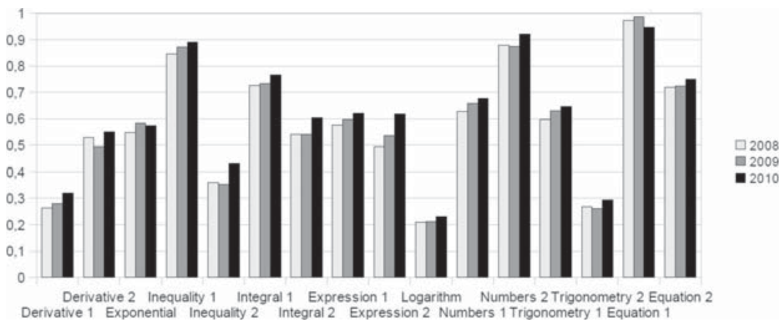

FIGURE 4. Distribution of the points of each exercise of the Basic Skills Test of mathematics in years 2008–2010. The length of the pillar describes average marks from the problem assignment (the maximum is 1).

The correlation between the results of the Basic Skills Test and the results of first year mathematics courses in 2009 were examined by using Spearman's rank correlation coefficient. This method does not require the Gaussian distribution of variables (Heikkilä 2005). The correlation was not very high but statistically significant ($\rho=0.2364$; $p=0.0000$).

When examining students who got four points or less from the Basic Skills Test (BST) in 2009 and attended the basic course of mathematics (N=64, 10%) we have found that this group fared weakly in basic courses (see Table 2). In Aalto University courses are graded by using the scale where 0 means that student fails the course, 1 is the lowest grade for passing the course and 5 is the highest grade. The most common grade was 2 and the mean grade was 2.03. The contents of the basic courses of mathematics vary and more specific analysis of the correlations is going to be made in the future.

TABLE 2. Crosstabulation of the course grade and points from the Basic Skills Test (BST) in 2009.

	Course grade						**Total**
BST pts	0	1	2	3	4	5	
4 points or less	13 20.31%	12 18.75%	16 25.00%	11 17.19%	7 10.94%	5 7.81%	64 100%
More than 4 points	81 13.94%	59 10.15%	96 16.52%	114 19.62%	113 19.45%	118 20.31%	581 100%
Total	94 14.57%	71 11.01%	112 17.36%	125 19.38%	120 18.60%	123 19.07%	645 100%

Results of the learning styles questionnaire

In the autumn 2009 203 students (24%) and in the autumn 2010 431 students (52%) answered to the learning styles questionnaire. In 2010 the answer rate was higher probably because of the earlier sending time and reminder e-mail. The *r x c-test* (Milton & Arnold 2003) was used for testing the homogeneity of these two samples. Results of the *r x c-test* showed that the distributions in the active/reflective, sensing/intuitive and visual/verbal scales were homogeneous. However in the sequential/global scale results were not homogeneous. In 2010 there were more neutral results than in 2009.

In Figure 5 you can see the distributions of each four dimensions in 2010. The mean for active/reflective scale was 3.1 and for sequential/global scale 3.26. The mean for sensing/intuitive scale was 3.77 and for the visual/verbal scale 3.73 which means that students tend to be more sensing and visual learners. According to this study and Jorma Vainionpää's (2006) study the communication science students in Tampere University tend to be more intuitive and global learners than the engineering students.

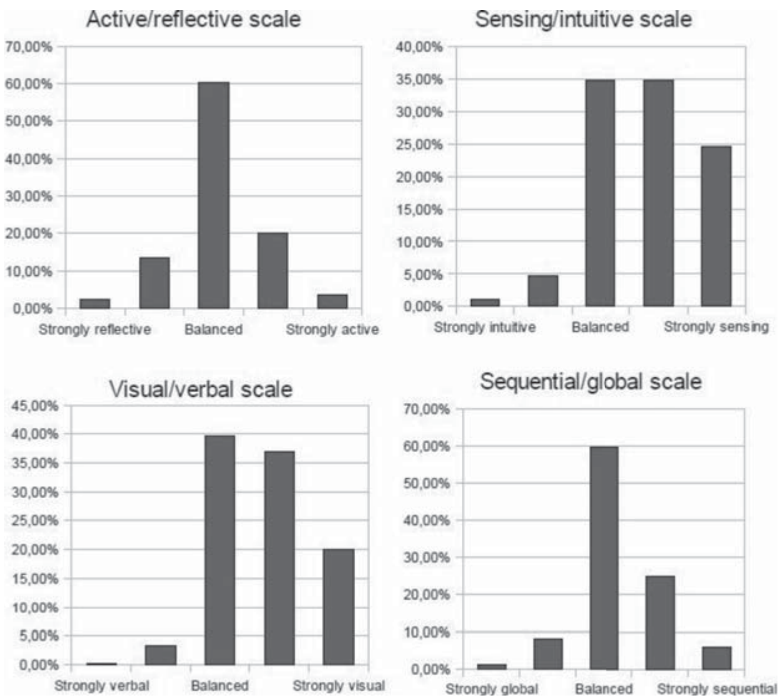

FIGURE 5. Distributions of Aalto University's engineering students in each learning style dimension in ILS-questionnaire in 2010 (N=431).

Discussion

According to the results of the Basic Skills Test of mathematics engineering students have many gaps in mathematics skills when they start their university studies. There are some very high profilated degree programs that draw highly skilled and motivated students nation-wide. Students who are in these programs tend to get better results from the Basic Skills Test, which might skew the distributions. In these degree programs there are also more difficult mathematics courses so students will not get good grades as easy as in basic courses. Thus the results of the first year mathematics courses are not directly comparable.

There were only few students who got less than three points from the test. There was couple of very elementary questions in the test so students who are accepted to the Aalto University should be able to solve them. One reason for weak success could be that many students have not come to university straight from the high school but they have had gap years before starting their studies. In Tampere University of Technology has been noticed that the more gap years students had, the weaker their success was in Basic Skills Test (Pohjolainen et al. 2006).

An important observation has been that success in the Basic Skills Test does not ensure success in mathematics studies. There is only a moderate correlation between the results of the Basic Skills Test and the results of the first year mathematics courses. There were significant number of students who got few points from the Basic Skills Test but high course grades and vice versa. Thus there has to be also other factors that influence success in mathematics courses. Other factors that also are believed to be important are, for example, motivation, ability to independent working and acclimatization to university studying environment. New students need also supportive actions for ensuring improved level of achievement in mathematics. Among actions taken to improve the situation are introduction of some e-learning material, for example automatic assessed STACK-exercises (Harjula 2008; Sangwin 2004), web-based review material concerning high school mathematics and mathematics workshops for students who want to solve exercises by the help of an instructor or in a group.

It seems that it would be useful to give the students who get a weak result in Basic Skills Test some revision material or lessons of high school topics. In Tampere University of Technology such system has been used (Pohjolainen et al. 2006; Huikkola et al. 2008). The remedial instruction there has been an obligatory part of weakly performing students' (five points or less from the Basic Skills Test) mathematics studies. In Aalto University we have created some web-based remedial material but the use of it is voluntary for students at the moment.

Even though the answering to the learning styles questionnaire was also voluntary, the answer rate in 2010 was quite high. According to earlier studies engineering students tend to be active, sensing, visual and sequential learners (Felder & Silverman 1988; Zywno 2002; Booth 2008).

One reason for the difference could be that in Finland more subjects are classified as engineering subjects than in other countries. The learning styles of Finnish engineering students have not been studied in this volume. The correlation between learning styles and results of the Basic Skills Test of mathematics was also measured but no strong correlation was found.

Studies have shown that there are mismatches between learning styles of engineering students and traditional teaching styles of engineering teachers (for example Felder & Silverman 1988). Most of the engineering students in Aalto University are visual learners so teachers should use more visual elements, for example charts and figures, in their teaching. For sensing learners there should be more "learning by doing" exercises, if possible. Some work to this direction has been done. However there are also many other factors, for example level of motivation and approaches to learning that have important implications for learning (Erkkilä & Koivukangas 2010; Felder & Brent 2005). Thus more studies are needed in the future to study these factors.

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Research paper

Automatic assessment in engineering mathematics: evaluation of the impact

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Abstract

We study the impact of a web-based automatic assessment system STACK in teaching mathematics for engineering students. We describe several uses of automatic assessment which have been tested in Aalto University during the past few years. We measure the impact of e-assessment to learning outcomes in engineering mathematics. This question is motivated by the practical need to show that the system is, in general, worth the effort invested but also our wish to better understand the learning process. The secondary aim is to obtain information about the different factors affecting the learning outcomes that would be useful in further improving mathematics teaching. Our goal is to show that such system can significantly activate students, allow much increased flexibility in practical arrangements of teaching, and facilitate innovative practices in, e.g., diagnostic testing and grading students' work.

Keywords: Automatic assessment, mathematics, progressive assessment

1. Introduction

Computer aided assessment (CAA) system STACK has been used in Aalto University School of Science and Technology since 2006. The system consists of a computer algebra system (CAS) for evaluating symbolic expressions, a web-based user interface, and a database for storing the exercise assignments and the student solutions. STACK is an open source software licensed under the GPL [7]. It was originally developed by C. Sangwin [16, 17] in the University of Birmingham, but the system has been further adapted for the requirements of engineering mathematics courses in Aalto University [8, 14]. For a technical description of the system and basic examples about its applications, we refer to [8] and [13]. Since the initial testing in 2006, the system has been taken into use for almost all engineering mathematics courses at Aalto University. In fact, we believe that we are the largest user of STACK in the world at the time of writing this paper.

We consider three particular applications of STACK. First, we briefly outline results from the diagnostic mathematics starting skills testing by using STACK that has been introduced to all our new students in 2008 and 2009. Second, we study experiences on automatically assessed exercise assignments on the course Mat-1.1210 Basic course in mathematics S1. It is the first of the three compulsory mathematics courses for electrical and telecommunications engineering students. About 200 first year students enrol to this course each year, and automatic assessment has been used since year 2007. Third, we discuss the motivation and results of the experimental course Mat-1.2991 Discrete mathematics which was taken by 58 students. About half of the students were computer engineering majors. In this course, web-based automatically assessed problem assignments constituted also an essential part of the final grade. The goal of this experiment was to activate students, and to balance their workload more evenly throughout the duration of the course. In the both courses, STACK was used as a component in blended learning [6]; i.e., traditional lectures and exercise sessions were used together with e-assessment. We remark that also pure e-learning approaches have been experimented with [2] but in too small scale to provide sufficient data for statistical analysis.

2. Review of literature

CAA has been relatively popular in teaching computer science, and the impact of e-assessment has been studied in [1, 9] and [19]. To our knowledge, no wide-scale research of the impact of using such system in teaching mathematics, at least not at university level, has been pursued earlier.

E-learning methodologies in teaching university level mathematics have been studied by M. Nieminen [11], although his recent PhD thesis does not involve e-assessment. In the study, course results were compared by covariance analysis: scores of the final tests were scaled to correspond to each other by means of the item response theory. The main conclusion was the following: there is no statistically significant difference between the results of the students who studied on an on-line course compared to those who were attending traditional lecture-based teaching. Some problems with the technology were reported; the training portal proved unsuitable for studying mathematics. These findings underline a need for specialised software (such as STACK) for teaching mathematics.

3. Research problems and methodology

The main objective of this research is to measure the impact of e-assessment to learning outcomes in engineering mathematics. This question is motivated by the practical need to show that the system is, in general, worth the effort invested but also our wish to better understand the learning process. The secondary aim is to obtain information about the different factors affecting the learning outcomes that would be useful in further improving mathematics teaching.

It is a difficult question in itself what we should understand by learning outcomes. In principle, there are three main philosophical world views one should consider here: positivist, constructivist and pragmatist. Positivists hold a deterministic view about the expected causes that determine effects or outcomes of human actions. The positivist viewpoint emphasizes the role of the underlying causes (or laws) to be discovered using experiments and statistical testing of data. Constructivists, on the other hand, hold the assumption that individuals seek to understand the world where they live and work in their own terms, thus making it crucial for the researcher to describe their subjective experiences. Consequently, methodologies related to constructivist studies are usually qualitative. The third position, arising from the philosophy of Peirce and others, is pragmatism. As a world view, pragmatism refers to actions, situations, and observed consequences rather than inferences from preceding events and circumstances as in positivism. There is a concern of what works, and how. Instead of focusing on methods, pragmatists emphasize the research problems and use all available means to understand them. [5]

In this study, we adopt the pragmatist position for practical and philosophical reasons given below. First, it would be difficult to arrange a large scale experiment in real world conditions that would be controlled enough to provide reliable and systematic data of experiments leading to positive knowledge. Indeed, skills and attitudes of new students change from year to year, and it is problematic to accurately measure if this has relevance to the conclusions. However, the starting skills test (considered later in this paper) is a partial solution, but it has been only available since 2008. We do not have comparable earlier data. Subjective learning experiences involving automatic assessment are certainly interesting, and they remain an object for future studies. On the other hand, the constructivist view is at odds with the practical motivations of our research which have an inherit perspective of an outside observer – we aim to show that automatic assessment is applicable and useful in large scale teaching. During the past few years, we have gathered comprehensive data concerning first and second study year, covering both coursework and success in examinations. The main research methodology in present study is statistical analysis of data observed in the real world conditions, supplemented with interviews.

We also take somewhat controversial view that learning outcomes are accurately measured by the standard tests used for grading students. This view can be defended by the practical motivation of our study: the success of teaching is mainly measured by the same metrics. Obviously, this view has its limitations as essential qualitative changes may remain undetected. For example, some studies [9, 19] indicate that e-assessment may stipulate thinking skills and facilitate deep learning. Because such change is not necessarily revealed in usual university mathematics exams, questions of this type are beyond the scope of the present research. As a secondary topic, we study the students experiences with the system, and how they prefer to use it. Questions about the costs and human resource requirements are discussed, too.

4. The basic skills test

New engineering students have been tested for their basic skills in mathematics in autumns 2008 and 2009. The same test will be used also in autumn 2010. The main advantage of test is that it the same problems are used annually, enabling comparisons to the data from previous years. The test problems were originally created in Tampere University of Technology but the assessment system used there was different because of software licence issues [18]. At Aalto University, STACK was used for the test which consists of 16 randomised problems covering the most important topics in high school mathematics. Because the test was a part of a compulsory course for engineering students nearly all new students were tested. Testing took places in a computer classroom. There was an instructor present supervising the test and answering technical questions. The test results are summarized in Figure 1. The test scores are mainly used as a normalising factor in this study; for a more complete review of results see [12, 18].

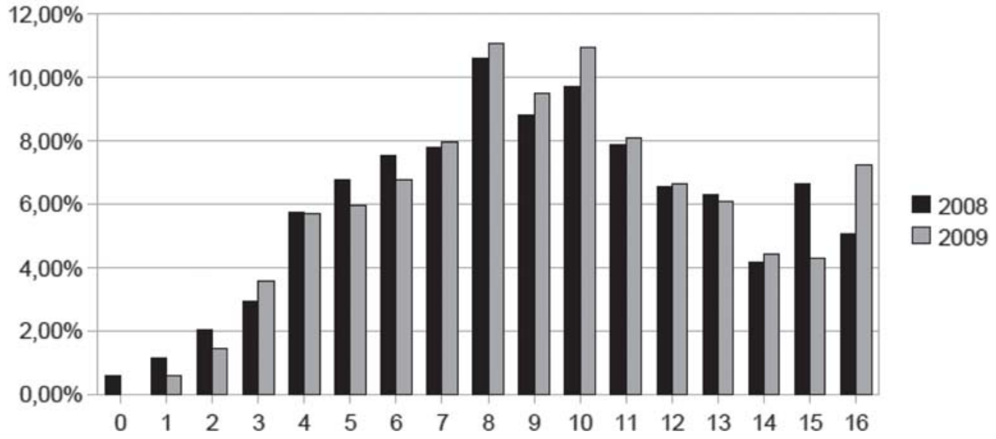

Figure 1. Distribution of the scores in the basic skill test of mathematics: years 2008 (N=889) (black) and 2009 (N=843) (gray). The length of the pillar describes the proportion of the total population with the score (0–16).

5. Experiences from the course S1

Basic course in mathematics S1 is the first of the three compulsory mathematics courses for electrical and telecommunications engineering students. It is intended to provide the basic skills needed in the degree program concerning the subject matter of the course. To contents of the course are complex numbers, matrix algebra, linear systems of equations, eigenvalues, differential and integral calculus for functions of one variable, introductory differential equations and Laplace transforms. Automatic assessment with STACK was first implemented on the course in 2007, and the same problems have been used on the course thereafter. The course also includes lectures and traditional exercise sessions supervised by an instructor. All lectures and exercises on the course are voluntary; students can choose only to participate on exams.

Table 1. Spearman's rank correlation between the basic skills test, the exercise and the exams scores on the course S1 on years 2007–2009. P-values are less or equal to p=0.0000, except for basic skills test in 2009 where p=0.0002.

Year	Basic skills	Traditional	STACK
2007	n/a	0.49	0.57
2008	0.45	0.67	0.71
2009	0.35	0.69	0.66

Statistical analysis of the results from this course (see Table 1) shows that the amount students training with the system has a significant correlation to their scores from exams. Clearly, the number of problems a student tried to solve explains the success in examinations much better than the starting skills, supporting the popular belief that mathematics is mostly learned by practising with many problems. Web-based problems have a better correlation to success in exams than traditional ones in 2007. The reason for this is probably plagiarism, which is much harder with e-assessment if randomisation is used. Interestingly, the difference vanishes after 2007, pointing to a possible change in the study culture. The student activity as increased significantly, in particular among the best students (Table 2). It is more difficult to assess actual effects of STACK to the learning outcomes. We have observed certain improvement in students skills in examinations. The level of improvement seems to be most significant among the best students, and in routine test problems that can be solved algorithmically. However it is difficult to quantify the effects of this. Independent studies [15] have shown a significant increase in the proportion of new students in telecommunications engineering who pass a basic course in mathematics in their first study year since e-assessment was introduced. The student activity hours (for all mathematics courses using STACK, years 2009–2010) are illustrated in Figure 2. As it was found in [13] it seems that many students prefer to work outside the office hours, possibly because of schedule conflicts. Flexibility of schedules is a key advantage of e-learning over traditional classroom teaching.

Table 2. The percentage of automatically assessed (above) and traditional (below) exercise assignments solved by students. Numbers are sorted presented by the grade given (0–5), where 0 means failing the course. The general level of activity among the failing students is very low.

	0	1	2	3	4	5
2007	11.60% 3.78%	17.97% 7.77%	33.02% 20.19%	31.19% 9.40%	64.04% 26.84%	79.68% 61.61%
2008	13.20% 4.79%	23.62% 13.56%	36.55% 16.15%	49.56% 28.85 %	65.60% 56.81%	74.89% 58.44%
2009	14.62% 3.77%	23.28% 10.00%	38.78% 29.20%	49.53% 50.48%	51.16% 68.22%	78.32% 92.48%

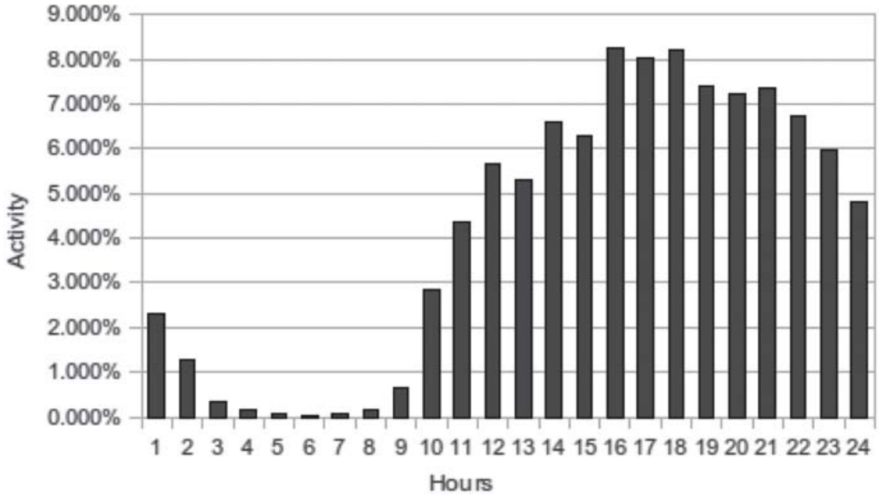

Figure 2. Student activity hours e-assessment system in Aalto University for nine mathematics courses using STACK. The relative frequency of submitted student solutions by hour. Total 93339 students submissions have been registered in 2009 – 2010.

6. Continuous evaluation with automatic assessment

Encouraged by our good experiences about e-assessment, an experimental course Discrete mathematics was set up at the spring semester 2010 (see also [3, 10]). The main idea was that the exercise assignment would form a significant portion of the final grade – a student could even pass the course without going to an exam. This approach follows the progressive, or continuous, assessment model [4, p. 192 – 193]. The model is certainly not new but it is difficult (or at least resource intensive) to implement effectively on a large course because of often resulting plagiarism. Again, the blended learning model was used: classroom lectures and face-to-face exercise sessions were held alongside the e-assessment, although use of STACK was extensive compared to the earlier experiments. The grading used on the course is illustrated in Figure 3.

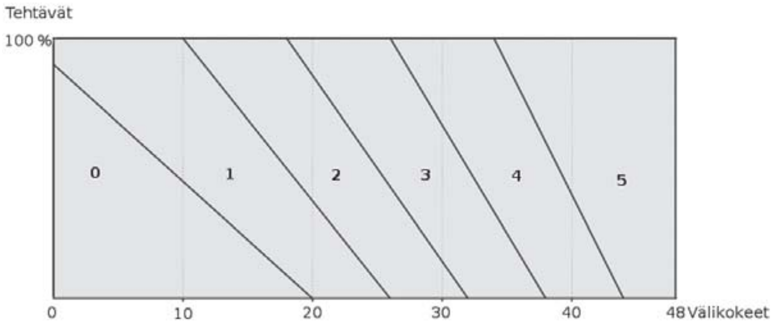

Figure 3. The grading system on the course Discrete mathematics: proportion of exercises solved is on the y-axis and exam score (0 – 48 points) is on the x-axis. The grades are 0 (fail) and 1–5, where 1 is the least passing grade and 5 is the best.

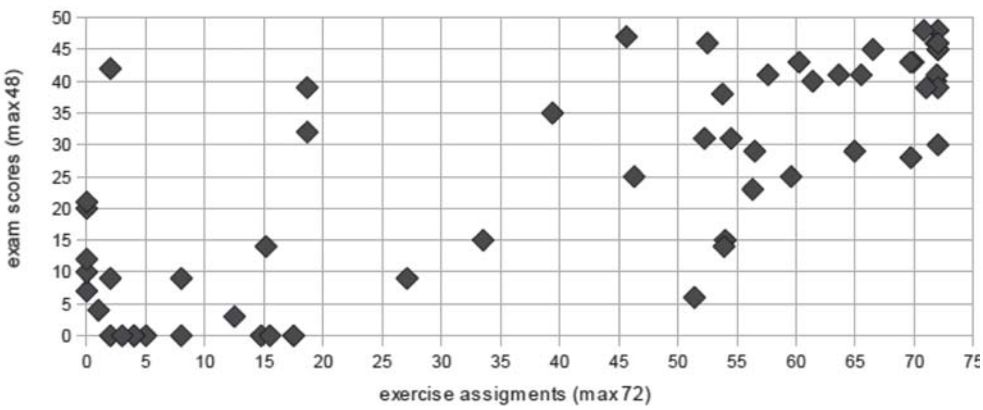

Figure 4. Student scores from exams and exercises by the time of the mid-term examination. About 29% of students have solved more than 90% of exercises.

Scores from exams and exercise assignments are illustrated in Figure 4. It is clear that the grading system for the course is highly motivating for students. Correlations of exercises and exam scores are given in Table 3. There are some examples of students who could solve a problem assignment when working with the e-assessment system, but could not solve a very similar one in the exam. This is particularly surprising because solutions to the problems cannot be easily copied when using e-assessment, and thus it is likely that the students solved their problem assignments by themselves. A likely explanation for such failure is stress in the examination situation, but this question requires further investigation.

Table 3. Spearman's rank correlations between exercise activity and scores from the exam scores. The results are similar to those of the course S1.

Correlations	Traditional	STACK
Exam score	0.69	0.73

After the course, feedback was collected from students. Questions where asked by using a five point Likert scale, but there was also an option for free form feedback. Overall, the feedback from the course was overwhelmingly positive both regarding the course arrangements and the technology. For example, only one student agreed, and nobody strongly agreed with the statement "STACK system was difficult to use". Based on the feedback, most of the students saw STACK as very useful for learning basic mathematical concepts and techniques, although many wished for even more comprehensive feedback concerning submitted solutions. On the other hand, students generally believed that learning advanced theoretical concepts and applications still requires face-to-face interaction with teacher. This is a key argument for using the blended learning model as in the pilot course. A more comprehensive analysis of the data is given in [10]. The grading system will be further piloted on other courses in the near future.

7. How much does it cost?

A question of practical importance is: how much does it cost, and is it worth the investment? According to our experience, creating a set of randomised, pedagogically meaningful problems for a full-semester 10 ECTS credit course required about three months of programming work. It should be noted that few people have both technical skill and teaching experience required for creating meaningful problem assignments. We have found that a system where the responsible teacher (lecturer) of the course works together with a programmer leads to a result which is good from both the pedagogical and technical point of view. STACK itself is free open source software, but running it requires a computer server. On the other hand, using STACK saves work after it has been properly set up, and thus fewer teaching assistants are required. By using this baseline analysis, we have found that the cost of creating a STACK exercises and introducing the system to a new course is paid back in four to five years.

8. Conclusions

E-assessment is a highly useful tool that can lead to increased flexibility in teaching. It also provides opportunities for improved feedback for students, diagnostic testing, data gathering and novel practices in practical arrangements of courses. Our experiences have shown that e-assessment is suitable for large scale teaching of engineering mathematics, it does not lead to overwhelming technical problems, and it can be highly motivating for the students. Besides these benefits, the system may lead to cost savings, at least in the long run.

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Appendix A

Index of Learning Styles Questionnaire

1. I understand something better after I

    try it out.

    (a) think it through.

2. I would rather be considered

    (a) realistic.

    (b) innovative.

3. When I think about what I did yesterday, I am most likely to get

    (a) a picture.

    (b) words.

4. I tend to

    (a) understand details of a subject but may be fuzzy about its overall structure.

    (b) understand the overall structure but may be fuzzy about details.

5. When I am learning something new, it helps me to

    (a) talk about it.

    (b) think about it.

6. If I were a teacher, I would rather teach a course
   (a) that deals with facts and real life situations.
   (b) that deals with ideas and theories.
7. I prefer to get new information in
   (a) pictures, diagrams, graphs, or maps.
   (b) written directions or verbal information.
8. Once I understand
   (a) all the parts, I understand the whole thing.
   (b) the whole thing, I see how the parts fit.
9. In a study group working on difficult material, I am more likely to
   (a) jump in and contribute ideas.
   (b) sit back and listen.
10. I find it easier
    (a) to learn facts.
    (b) to learn concepts.
11. In a book with lots of pictures and charts, I am likely to
    (a) look over the pictures and charts carefully.
    (b) focus on the written text.
12. When I solve math problems
    (a) I usually work my way to the solutions one step at a time.
    (b) I often just see the solutions but then have to struggle to figure out the steps to get to them.
13. In classes I have taken
    (a) I have usually gotten to know many of the students.
    (b) I have rarely gotten to know many of the students.
14. In reading nonfiction, I prefer

   (a) something that teaches me new facts or tells me how to do something.
   (b) something that gives me new ideas to think about.

15. I like teachers
    (a) who put a lot of diagrams on the board.
    (b) who spend a lot of time explaining.

16. When I'm analyzing a story or a novel
    (a) I think of the incidents and try to put them together to figure out the themes.
    (b) I just know what the themes are when I finish reading and then I have to go back and find the incidents that demonstrate them.

17. When I start a homework problem, I am more likely to
    (a) start working on the solution immediately.
    (b) try to fully understand the problem first.

18. I prefer the idea of
    (a) certainty.
    (b) theory.

19. I remember best
    (a) when I see.
    (b) when I hear.

20. It is more important to me that an instructor
    (a) lay out the material in clear sequential steps.
    (b) give me an overall picture and relate the material to other subjects.

21. I prefer to study
    (a) in a study group.
    (b) alone.

22. I am more likely to be considered
    (a) careful about the details of my work.
    (b) creative about how to do my work.

23. When I get directions to a new place, I prefer
    (a) a map.
    (b) written instructions.
24. I learn
    (a) at a fairly regular pace. If I study hard, I'll ”get it.”
    (b) in fits and starts. I'll be totally confused and then suddenly it all ”clicks”.
25. I would rather first
    (a) try things out.
    (b) think about how I'm going to do it.
26. When I am reading for enjoyment, I like writers to
    (a) clearly say what they mean.
    (b) say things in creative, interesting ways.
27. When I see a diagram or sketch in class, I am most likely to remember
    (a) the picture.
    (b) what the instructor said about it.
28. When considering a body of information, I am more likely to
    (a) focus on details and miss the big picture.
    (b) try to understand the big picture before getting into the details.
29. I more easily remember
    (a) something I have done.
    (b) something I have thought a lot about.
30. When I have to perform a task, I prefer to
    (a) master one way of doing it.
    (b) come up with new ways of doing it.
31. When someone is showing me data, I prefer
    (a) charts or graphs.

(b) text summarizing the results.

32. When writing a paper, I am more likely to

    (a) work on (think about or write) the beginning of the paper and progress forward.

    (b) work on (think about or write) different parts of the paper and then order them.

33. When I have to work on a group project, I first want to

    (a) have "group brainstorming" where everyone contributes ideas.

    (b) brainstorm individually and then come together as a group to compare ideas.

34. I consider it higher praise to call someone

    (a) sensible.

    (b) imaginative.

35. When I meet people at a party, I am more likely to remember

    (a) what they looked like.

    (b) what they said about themselves.

36. When I am learning a new subject, I prefer to

    (a) stay focused on that subject, learning as much about it as I can.

    (b) try to make connections between that subject and related subjects.

37. I am more likely to be considered

    (a) outgoing.

    (b) reserved.

38. I prefer courses that emphasize

    (a) concrete material (facts, data).

    (b) abstract material (concepts, theories).

39. For entertainment, I would rather

    (a) watch television.

    (b) read a book.

40. Some teachers start their lectures with an outline of what they will cover. Such outlines are

    (a) somewhat helpful to me.

    (b) very helpful to me.

41. The idea of doing homework in groups, with one grade for the entire group,

    (a) appeals to me.

    (b) does not appeal to me.

42. When I am doing long calculations,

    (a) I tend to repeat all my steps and check my work carefully.

    (b) I find checking my work tiresome and have to force myself to do it.

Appendix B

Index of Learning Styles Questionnaire in Finnish

1. Ymmärrän asian paremmin sen jälkeen kun
   (a) kokeilen sitä.
   (b) käyn sen mielessäni läpi.
2. Minua pidetään pikemminkin
   (a) realistisena.
   (b) innovatiivisena.
3. Kun ajattelen, mitä tein eilen, tulee todennäköisemmin mieleeni
   (a) kuvia.
   (b) sanoja.
4. Minulle on tyypillistä
   (a) ymmärtää jonkin sisällön yksityiskohdat, mutta kokonaisuuden rakenne saattaa jäädä hämäräksi.
   (b) ymmärtää kokonaisuuden rakenne, mutta yksityiskohdat saattavat jäädä himmeiksi.
5. Kun olen opettelemassa jotain uutta, minulle on avuksi

   (a) puhua siitä.
   (b) ajatella sitä.

6. Jos olisin opettaja, niin vetäisin mieluummin kurssia
   (a) joka käsittelee konkreettisia asioita.
   (b) joka käsittelee periaatteita ja teoreettisia kysymyksiä.

7. Hankin mieluummin uutta tietoa
   (a) kuvista, diagrammeista tai kartoista.
   (b) kirjallisista tai suullisista ohjeista.

8. Kun olen ymmärtänyt
   (a) kaikki osatekijät, tajuan kokonaisuuden.
   (b) kokonaisuuden, tajuan miten osatekijät siihen liittyvät.

9. Kun olen jossain työryhmässä vaikean asian kimpussa, olen taipuvaisempi
   (a) panemaan toimeksi ja ryhtymään ideoimaan.
   (b) ottamaan mukavan asennon ja kuuntelemaan.

10. Minulle on helpompaa
   (a) oppia konkreettisia asioita.
   (b) oppia käsitteitä.

11. Kirjasta, jossa on paljon kuvia ja kaavioita, pyrin todennäköisesti
   (a) tutkimaan tarkasti kuvia ja kaavioita.
   (b) keskittymään tekstiin.

12. Kun ratkaisen matemaattisia tehtäviä
   (a) etenen yleensä ratkaisuihin vaiheittain.
   (b) usein jotenkin vain näen ratkaisun ja minun pitää ponnistella löytääkseni siihen johtaneet vaiheet.

13. Osallistumillani kursseilla
   (a) olen yleensä tutustunut moniin opiskelijoihin.
   (b) olen harvemmin tutustunut useampiin opiskelijoihin.

14. Asiateksteistä pidän parempana niitä,
    (a) joista opin uusia asioita tai miten tehdä jotain.
    (b) joista saan uusia ajatuksia pohdittavaksi.
15. Pidän opetuksesta,
    (a) jossa käytetään paljon taulua ja kuvia.
    (b) jossa käytetään runsaasti aikaa asioiden selittämiseen.
16. Analysoidessani tehtäväksi annettua tarinaa tai romaania
    (a) ajattelen sen tapahtumia ja yritän pohtia niitä vastatakseni annettuihin tehtäviin.
    (b) tehtävät ovat mielessä lukiessa, lopuksi palaan tekstiin ja etsin tehtävien edellyttämät tapahtumat.
17. Kun alan ratkaista tehtäväksi annettua ongelmaa, todennäköisesti
    (a) alan heti etsiä ratkaisua.
    (b) yritän ensiksi täysin ymmärtää ongelman.
18. Pidän parempana ajatusta
    (a) varmuudesta.
    (b) teoriasta.
19. Muistan parhaiten
    (a) sen, minkä näen.
    (b) sen, minkä kuulen.
20. Minulle on tärkeämpää se, että opettaja
    (a) esittää sisällön selkeästi vaiheittain.
    (b) antaa yleiskuvan sisällöstä ja liittää sen muihin asioihin.
21. Opiskelen yleensä mieluummin
    (a) ryhmässä.
    (b) yksin.
22. Minua pidetään todennäköisemmin

(a) tarkkana työni yksityiskohdissa.
(b) luovana työni tekemisessä.

23. Kun saan neuvoja johonkin outoon paikkaan menemisessä, pidän parempana
    (a) karttaa.
    (b) kirjallisia ohjeita.

24. Opin
    (a) suhteellisen tasaiseen tahtiin. Kunhan vain opiskelen lujasti, ”tajuan jutun juonen”.
    (b) puuskittain. Saatan olla ymmälläni ja sitten vain kaikki ”naksahtaa paikoilleen”.

25. Mieluummin ensin
    (a) kokeilisin asioita.
    (b) ajattelisin, kuinka tekisin sen.

26. Kun luen vapaa-aikanani, toivoisin kirjoittajien
    (a) ilmaisevan selvästi, mitä tarkoittavat.
    (b) ilmaisevan asiat luovilla, kiinnostavilla tavoilla.

27. Kun näen kaavion tai piirroksen luokassa, muistan todennäköisemmin
    (a) kuvan.
    (b) sen, mitä opettaja sanoi.

28. Pohtiessani jotain sisältöä olen taipuvaisempi
    (a) keskittymään ensin sen yksityiskohtiin enkä ehkä heti näe kokonaisuutta.
    (b) yrittämään ymmärtää kokonaisuuden ennen kuin yritän päästä selville yksityiskohdista.

29. Muistan helpommin
    (a) sen, mitä olen tehnyt.
    (b) sen, mitä olen paljon ajatellut.

30. Kun minun on tehtävä jokin tehtävä, minusta on parempi
    (a) oppia hallitsemaan yksi tapa tehdä se.

(b) keksiä uusia tapoja sen tekemiseen.

31. Kun joku esittää minulle aineiston, pidän parempana
    (a) kaavioita ja graafisia esityksiä.
    (b) tekstiä, joka kokoaa tulokset yhteen.

32. Kun kirjoitan esseetä, minulle on tyypillistä
    (a) lähteä liikkeelle (ajattelemalla tai kirjoittamalla) esseen alusta ja työskentelemään siitä eteenpäin.
    (b) lähteä liikkeelle (ajattelemalla tai kirjoittamalla) esseen eri osista ja sitten kokoamaan ne yhteen.

33. Kun olen mukana ryhmätyössä, haluan aluksi
    (a) ryhmän aivoriihen, johon kaikki osallistuvat tuottamalla ideoita.
    (b) yksilöllistä aivoriihtä, jonka jälkeen kokoonnutaan yhteen vertailemaan ideoita.

34. Minusta on palkitsevaa kutsua jotakuta
    (a) järkeväksi.
    (b) mielikuvarikkaaksi.

35. Kun tapaan vaikkapa juhlissa ihmisiä, muistan todennäköisesti paremmin sen,
    (a) miltä he näyttivät.
    (b) mitä he kertoivat itsestään.

36. Kun opiskelen uutta asiaa, minulle sopii paremmin
    (a) keskittyä tuohon asiaan ja oppia siitä niin paljon kuin mahdollista.
    (b) yrittää löytää yhtymäkohtia tuon asian ja siihen liittyvien seikkojen välillä.

37. Minua pidetään todennäköisesti
    (a) seurallisena.
    (b) pidättyväisenä.

38. Pidän enemmän kursseista, joilla korostuu
    (a) konkreettinen materiaali (faktoja, aineistoja).
    (b) abstrakti materiaali (käsitteitä, teorioita).

39. Viihdykkeenäni pidän parempana
    (a) television katselua.
    (b) kirjan lukemista.

40. Jotkut opettajat aloittavat luentonsa jäsentämällä sen, mistä tulevat puhumaan. Tällaiset järjestelyt ovat minulle
    (a) jossain määrin hyödyllisiä.
    (b) erittäin hyödyllisiä.

41. Ajatus ryhmätenteistä tai -tehtävistä, joissa koko ryhmä saa yhteisen arvosanan
    (a) miellyttää minua.
    (b) ei miellytä minua.

42. Tehdessäni monivaiheisia laskutoimituksia
    (a) pyrin yleensä tarkistamaan kaikki vaiheet huolellisesti.
    (b) koen työn tarkistamisen rasittavaksi ja minun on pakotettava itseni tekemään se.

Appendix C

Index of Learning Styles Questionnaire in Swedish

1. Jag förstår någonting bättre efter att jag har
   (a) försökt göra det själv.
   (b) gått igenom det i mina tankar.
2. Jag anses snarare vara
   (a) realistisk.
   (b) innovativ.
3. När jag tänker pådet vad jag gjorde igår, kommer jag förmodligen ihåg
   (a) bilder.
   (b) ord.
4. Det är typiskt för mig
   (a) att förstådetaljerna i någonting, men helheten kan förbli otydlig.
   (b) att förståhelheten men detaljerna kan förbli oklara.
5. När jag lär mig någonting nytt, hjälper det mig om jag
   (a) pratar om det.

(b) tänker pådet.

6. Om jag var lärare skulle jag hellre hålla en kurs
   (a) som behandlar konkreta saker.
   (b) som behandlar principer och teoretiska fågor.
7. Jag skaffar ny information hellre med hjälp av
   (a) bilder, diagram eller kvartor.
   (b) skriftliga eller muntliga anvisningar.
8. När jag först har förstått
   (a) alla bidragande faktorer, förstår jag sedan helheten.
   (b) helheten, förstår jag sedan vad bidragande faktorerna har med det att göra.
9. När jag jobbar i en arbetsgrupp med någonting svårt, brukar jag
   (a) sätta igång och komma med idéer.
   (b) inta en bekväm ställing och lyssna.
10. Det är lättare för mig
    (a) att lära mig konkreta saker.
    (b) att lärä mig begrepp.
11. Om jag läser en bok som har massor av bilder och scheman kommer jag förmodligen att
    (a) granska bilder och scheman noggrant.
    (b) koncentrera mig påtexten.
12. När jag löser matematiska uppgifter
    (a) går jag oftast steg för steg till lösningen.
    (b) ser ser jag bara vad lösningen skall vara pånågot sätt och jag måste anstränga mig för att hitta de steg som ledde til den.
13. Påkurserna som jag har deltagit i
    (a) har jag ofta lärt känna många studerande.
    (b) har jag sällan lärt känna flera studerande.

14. Av saktexter föredrar jag dem
    (a) som lär mig nya saker eller hur jag ska göra någonting.
    (b) som ger mig nya åsikter att fundera på.
15. Jag tycker om undervisning,
    (a) där det används mycket bilder och tavlan.
    (b) där det läggs mycket tid påatt förklara saker.
16. När jag analyserar en roman eller en berättelse som har givits i uppgift
    (a) tänker jag pådess händelser och försöker fundera påoch samla dem för att svara påuppgiften.
    (b) har jag uppgiften i tankarna när jag läser texten och senare återkommer jag till texten och söker de händelser som hänför sig till uppgiften.
17. När jag börjar lösa ett problem som har givits i hemuppgift,
    (a) börjar jag förmodligen genast söka lösningen.
    (b) försöker jag förmodligen först förståproblemet i sin helhet.
18. Jag föredrar tanken om
    (a) säkerhet.
    (b) teori.
19. Jag minns bäst
    (a) det som jag ser.
    (b) det som jag hör.
20. Det är viktigare för mig, att läraren
    (a) förklarar innehållet tydligt steg för steg.
    (b) ger en allmän bild av innehållet och sedan anknyter det till andra saker.
21. Jag arbetar helst
    (a) i en arbetsgrupp.
    (b) ensam.
22. Jag anses vara

(a) noggran i detaljer i mitt arbete.
(b) kreativ i mitt arbete.

23. När jag får råd om hur jag ska ta mig till en främmande ort, föredrar jag
    (a) en karta.
    (b) skriftliga anvisningar.
24. Jag lär mig
    (a) i relativt jämn takt. Om jag bara studerar hårt, fattar jag idén med det hela.
    (b) ryckvis. Jag kan först känna mig ställd men sedan faller allt bara påplats .
25. Först skulle jag helst
    (a) pröva saker.
    (b) fundera hur jag ska göra det.
26. När jag läser under min fritid, hoppas jag att författaren
    (a) uttrycker sig tydligt.
    (b) uttrycker sig innovativt och intressant.
27. När jag ser ett schema eller en teckning i klassrummet, kommer jag senare ihåg
    (a) bilden.
    (b) det läraren sade.
28. När jag funderar pånågonting brukar jag
    (a) först koncentrera mig pådetaljerna och ser kanske inte genast helheten.
    (b) försöka förståhelheten innan jag försöker fåreda pådetaljer.
29. Jag minns lättast
    (a) det som jag har gjort.
    (b) det som jag har tänkt på.
30. När jag måste göra en uppgift, tycker jag att det är bättre
    (a) att lära mig behärska ett sätt att göra det.
    (b) att komma pånya sätt att göra det.

31. När någon visar mig någonting, föredrar jag
    (a) scheman och grafiska framställingar.
    (b) text som samlar ihop resultaten.
32. När jag skriver en essä, är det typiskt för mig
    (a) att sätta igång (tänka eller skriva) med början av essän och fortsättä framåt.
    (b) att sätta igång (tänka eller skriva) med olika delar av essän och sedan samla ihop dem.
33. När jag deltar i grupparbete, vill jag först ha
    (a) en kollektiv brainstorm, som alla gruppmedlemmar deltar i genom att ge idéer.
    (b) en individuell brainstorm, efter vilken alla samlas för att jämförä idéer.
34. Jag tycker att det är berömmande att kalla någon för
    (a) förnuftig.
    (b) uppfinningsrik.
35. När jag träffar folk påen fest, kommer jag senare förmodligen bättre ihåg
    (a) hur de såg ut.
    (b) vad de berättade om sig själva.
36. När jag studerar någonting nytt, passar det bättre för mig
    (a) att koncentrera mig pådet och lära mig såmycket om det som möjligt.
    (b) att försöka hitta beröringspunkter mellan det och andra saker som har med det någonting att göra.
37. Jag anses snarast vara
    (a) social.
    (b) försiktig av mig.
38. Jag tycker mer om kurser, som betonar
    (a) konkret material (fakta, data).
    (b) abstrakt material (begrepp, teori).

39. Som underhållning föredrar jag
    (a) att titta påtv.
    (b) att läsa en bok.
40. Några lärare börjar sina föreläsningar med att strukturera det som de ska tala om. För mig är sådana struktureringar
    (a) i någon mån nödvändiga.
    (b) mycket nödvändiga.
41. Idén om grupptentor eller -uppgifter där hela gruppen får ett gemensamt vitsord
    (a) tilltalar mig.
    (b) tilltalar mig inte.
42. När jag gör räkneoperationer med många steg
    (a) försöker jag granska alla steg ordentligt.
    (b) upplever jag granskningen som ansträngande och jag måste tvinga mig att göra det.