New engineering students' learning styles and basic skills in mathematics

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Abstract: 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 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
   - **(a)** try it out.
   - **(b)** 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.

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).

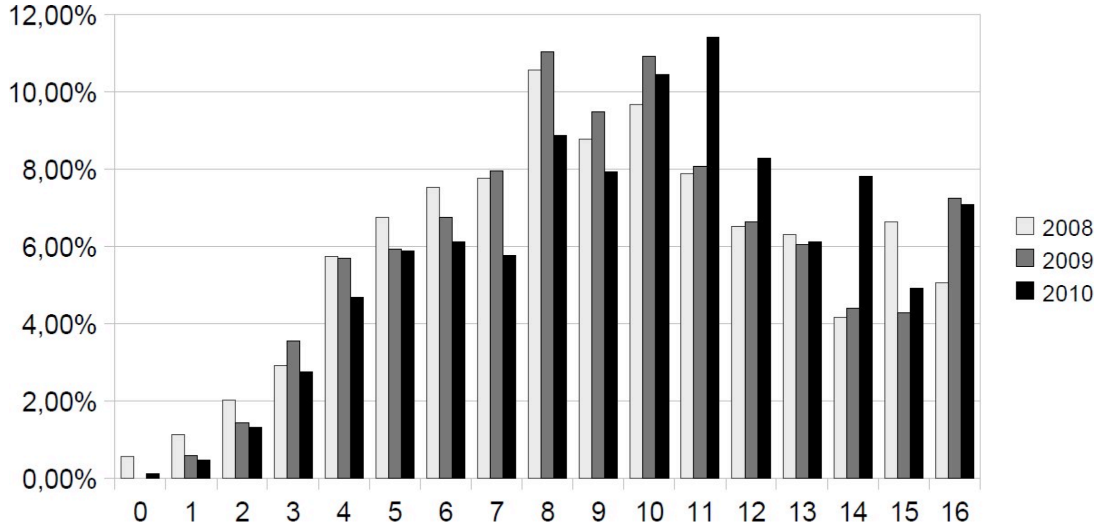

Figure 3: Distribution of the results of the Basic Skills Test of mathematics in years 2008-2010.

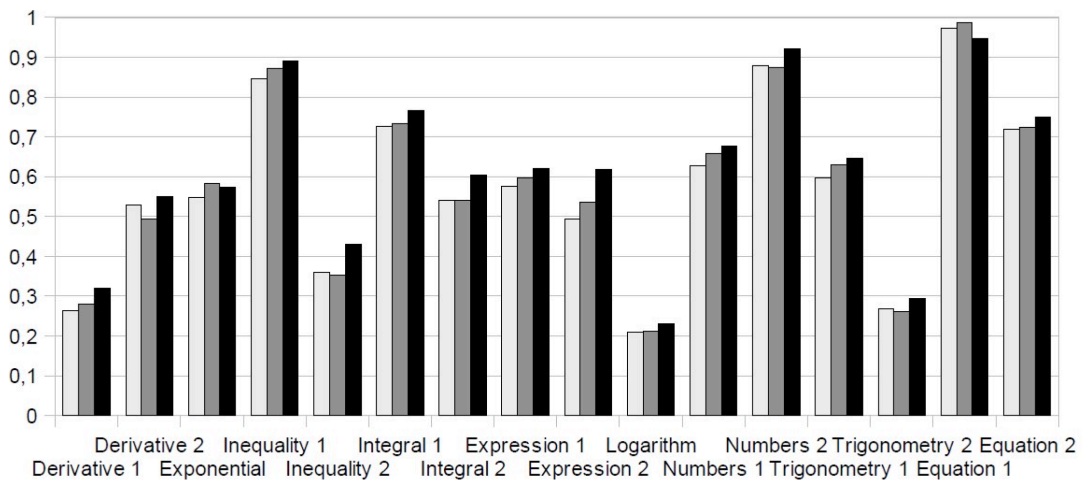

Figure 4: Distribution of the points of each exercise of the Basic Skills Test of mathematics in years 2008-2010. The length of the pillar describes average marks from the problem assignment (the maximum is 1).

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.

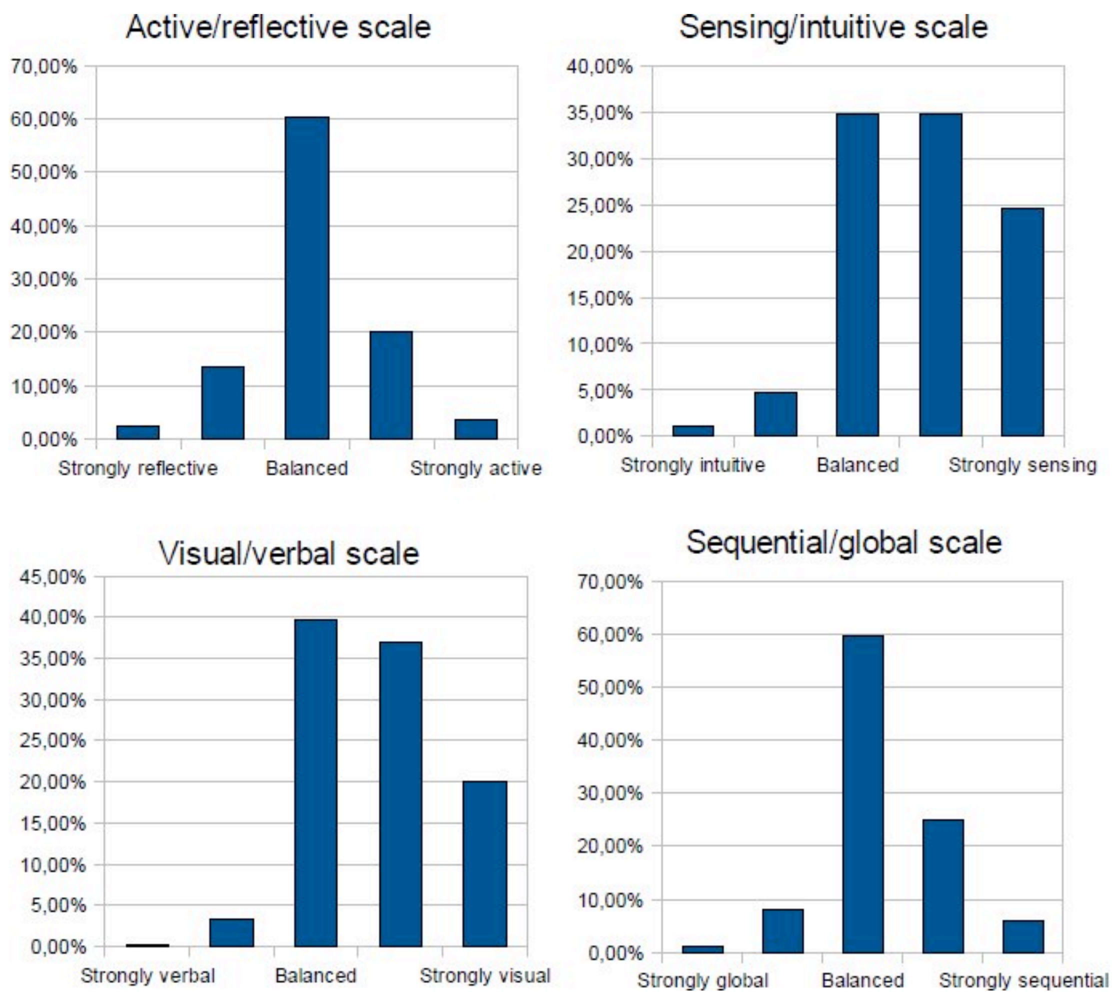

Figure 5: Distributions of Aalto University's engineering students in each learning style dimension in ILS-questionnaire in 2010 (N=431).

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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