Experiences of continuous formative assessment in engineering mathematics

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Abstract: We summarize preliminary results from an experimental engineering mathematics course Discrete Mathematics, where continuous formative assessment was used alongside with traditional examination based model. The primary goals of the experiment were to activate students by rewarding them for participation throughout the course and to provide them feedback of their progress in learning. Besides traditional methods of assessment, an on-line automatic assessment system was used. In order to measure if the goals were attained, a student survey was conducted by using a questionnaire which consisted of items related to the overall quality of the course as well as students' learning activites. An opportunity for free-form feedback was also given. While the data does not permit deep statistical analysis, the results in general were promising. Similar arrangements are currently being implemented on other engineering mathematics courses. The learning outcomes and the student survey are discussed and compared to available data from other engineering mathematics courses.

Keywords: engineering mathematics, engineering education, continuous assessment, blended learning

Introduction

One of the most important factors influencing learning, is the way students think they are going to be assessed (Biggs, 2003; Brown, Bull, & Pendlebury, 1997; Ramsden, 1992). As Lindblom-Ylänne and Nevgi (2002) have put it, assessment is the foundation of quality teaching. In other words, we must plan the assessment methods so that they encourage students to study the things we wish them to learn.

From the teacher's perspective, the course objectives define what and how students should learn. After the course the teacher assesses how well the objectives have been reached. From the students' point of view, the assessment defines what needs to be learned. Students plan their activities to perform well in the assessment. Those activities then lead to learning outcomes. This effect that assessment has on learning is called *backwash*. The key for making students to attain the course objectives is to align the assessment with them. (Biggs, 2003)

Research objectives and methodologies

Our view of learning is pragmatic; we are concerned of what works and how. The focus is to find answers to the research problems using all the available means to understand them. (Creswell, 2009) This point of view has been chosen, because the experimental course aims to give the students basic mathematical skills required in their future engineering studies. The content of the course is standard and it has been developed in collaboration with the other departments, so the freedom for changing learning objectives is limited.

One specific problem in teaching engineering mathematics has been the general passivity and lack of participation among the students. Clearly, if the students would practice more by solving voluntary exercise assignments, they would learn more effectively and also perform better in the exams. One way of increasing the student activity is, of course, introducing more obligatory work. However, we prefer to make the assignments more interesting, rewarding and flexible. For example, lack of independence (Ramsden, 1992) and perceptions of heavy workload (Lizzio, Wilson, & Simons, 2002) encourage surface learning approaches.

The results of our previous studies have shown that the activity of solving exercises during the course has increased particularly among the best students (Rasila, Havola, Majander, & Malinen, 2010). On our experimental course, which is described more thoroughly later, we changed the assessment procedures so that also the weaker students would be encouraged to actively solve the assignments. Our research questions were:

1. How do the students experience the quality of the course?
2. What kind of activities do the students participate on the course?
3. What are the students' learning outcomes? In particular, are there any differences in the outcomes compared to other engineering mathematics courses?

We performed limited statistical analysis to the data (Metsämuuronen, 2006), but this experiment was very small, and the data for comparison purposes was mostly not available. Further experimentation with the described method is going on, but analysis of the data is not yet available. However, the student feedback from the pilot course was highly encouraging.

Assessment theory

Purposes of assessment

Trotter (2006) has divided the purposes of assessment into three categories: giving feedback to students, motivating students and guiding students' learning. These categories outline the ways we expect the assessment to improve student learning, which should be the primary purpose of assessment. From the teacher's point of view we can also have secondary purposes: to provide diagnostic information to the teacher both about how well the class understands the topics and of students' individual understanding. (Garfield, 1994) In addition to these *developmental* purposes, the assessment usually has also *judgmental* purposes that provide an indicator of how well the students have achieved the course objectives. These are commonly considered to be important, because they are concerned with licenses to proceed to the next stage; for example to take a follow-up course or to graduate and start to work. (Brown et al., 1997)

It is usual that the judgmental purposes of assessment that should be regarded secondary are, in fact, dominating the assessment practices (Lindblom-Ylänne & Nevgi, 2002). If the developmental purposes are in contradiction with the judgmental ones, students easily resolve to surface learning strategies. (Brown et al., 1997)

Different types of assessment

The most common classification divides assessment in two categories according to its purpose: *formative* and *summative* assessment. Formative assessment takes place during the learning process. It is used for developmental purposes: to motivate and help students by showing them how their learning progresses. For the teacher the results of formative assessment tell what things are difficult for the students. This information can be used to improve teaching. The purpose of summative assessment is judgmental: to find out how well students have learned the things they should have learned. It is used mainly for grading students at the end of a course, although in practice, it often takes place during the course. (Biggs, 2003)

Formative assessment should be an important part of teaching. The effectiveness of teaching methods is greater if more formative feedback is provided to the students. Students should also be encouraged to take responsibility for their own formative assessment. This way they learn to assess their own learning, which is particularly important after they leave school and need to learn new things on their own. Both formative and summative assessment is based on performance, which is matched against the expected result. The difference is that, from a student's perspective summative assessment is final. On the other hand, students may even feel that formative assessment is not assessment at all. (Biggs, 2003)

It is commonly argued that formative and summative assessment should not be confused (Biggs, 2003; Miller, Imrie, & Cox, 1998). There is, however, a popular form of assessment that connects the two assessment types: *continuous assessment*. It means that we use frequent assignments during the course each of which contributes to the final result. The problem of confusing formative and summative assessment when using this procedure can be overcome (at least partially) by scaling the scores from assignments so that they weigh less in the final grade than the actual summatively assessed tasks. But Miller et al. (1998) do see some other problems with continuous assessment as well. We address these problems in the following chapter, where we describe the assessment procedures used on our experimental engineering mathematics course Discrete Mathematics in more detail.

Developing assessment in engineering mathematics

Traditional assessment, where the grade is awarded solely based on the course exams, has several shortcomings. As the grading is based only on a few exam questions, all topics of the course can not be covered and some question types get over-emphasized. The exams normally cover distinct parts of the course, and after taking the exam the students can forget everything they have learned. Because of the backwash, students often start studying only just before the exam which does not encourage deep learning (Ramsden, 1992). In addition, the exam situation can create anxiety.

Some practical difficulties related to the weekly exercises listed by Miller et al. (1998) are too slow feedback, heavy marking load and plagiarism. To solve these issues, we have from 2006 been using (Rasila, Harjula, & Zenger, 2007) and developing (Harjula, 2008) an automatic assessment system STACK to implement computer aided exercises. By using these exercises we can provide instant feedback to students, decrease teacher's work with computer aided marking and randomize exercise parameters to reduce the possibility of plagiarism.

In practice our continuous formative assessment uses blended learning with face-to-face interaction and computer aided assignments. This way the grading is based on a large amount of assignments, which means that the topics of the course are better covered and the significance of one task is not emphasized. At the same time the common issues mentioned above are addressed. Based on the backwash, this should also get students to distribute the workload more evenly during the whole course which encourages deep learning (Ramsden, 1992).

Quality in learning

To evaluate the quality of the course, we have to define what is meant by quality in learning. We use the definition of Harvey and Knight (1996), who present five approaches to quality. According to their division, quality can be regarded as:

1. exceptional,
2. perfection or consistency,
3. fitness for purpose,
4. value for money,
5. transformation.

Quality as exceptional is considered to be something outstanding, such as learning in a highly reputable university. The exceptional aspect of e-learning or blended learning is difficult to evaluate, because in this context the image of the quality is at least as important as the actual properties of the course. (Heikkilä, 2005) The other aspects, however, are easier to evaluate, so we concentrate on them. For further discussion see Rasila (2008).

The experimental course

When designing our experimental course Discrete Mathematics, we started off with the same basic learning sequence used on most of our courses (Figure 1). The significance of exercise scores was increased so that a student could pass the course without getting any points in exams if he/she solved at least 90 % of exercises (Figure 2). Obtaining almost the full exercise score required the student to have solved almost all exercises, which we interpreted so that he/she had to have at least minimum knowledge of the subjects covered at the course.

On the experimental course that took place in spring 2010, there were 58 students participating. They were mostly students between 2nd and 5th year and most of them (88%) were male. The main degree program of the students was Computer Science and Engineering (48%). The course included topics from combinatorics, number theory and algebra. There was one lecturer and one assistant on the course.

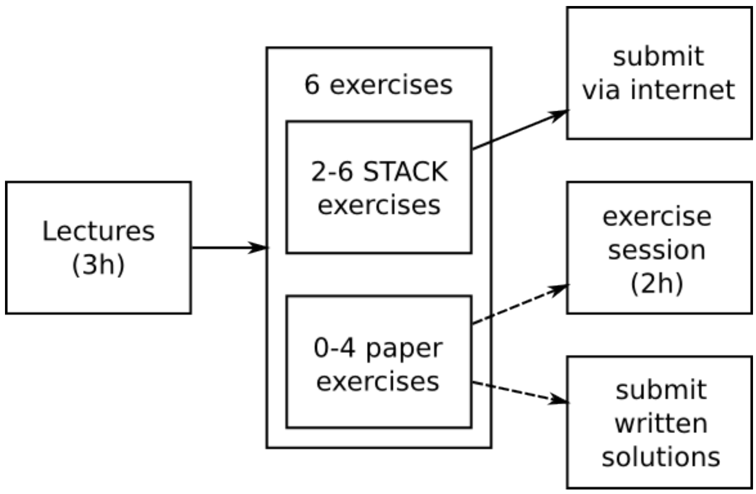

Figure 1. The learning sequence on the experimental course.

The course lasted for 12 weeks and was credited 5 ECTS. The learning sequence (Figure 1) for each week consisted of 3 hours of face-to-face lectures after which 6 exercises were assigned. Two or more of the exercises were computer aided STACK exercises which were to be submitted via internet. The rest of the exercises were traditional pen-and-paper exercises, which could either be solved in the weekly face-to-face exercise sessions or handed in as written solutions. The total number of exercise assignments during the course was 72, and about

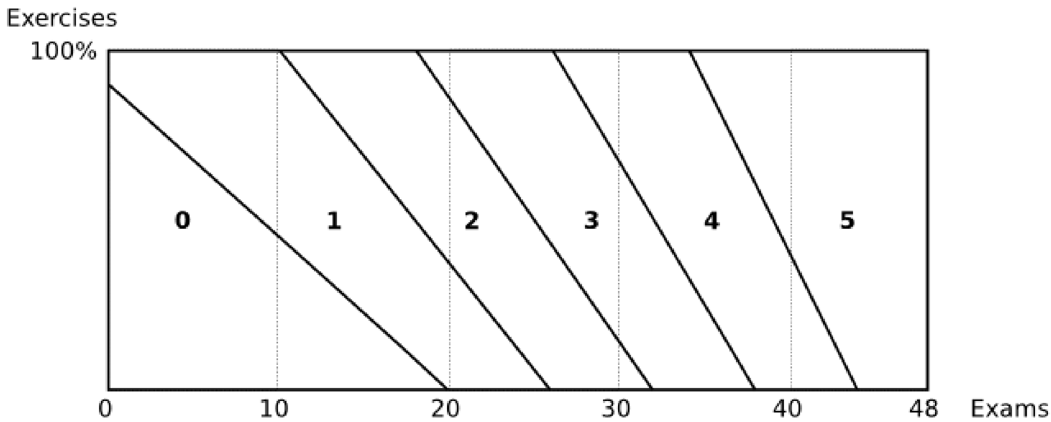

Figure 2. Grade limits on the experimental course; students could pass the course by solving 90% of the exercises (grade 0 means fail).

2/3 of these were STACK exercises. In addition, there were two voluntary exams.

Methods

Students' experiences

Our experiment was a one-shot case study, where the group of students participating on the experimental course was studied after using the assessment methods described above (Campbell, & Stanley, 1973). We used mixed methods with mostly quantitative approaches, but concerning students' experiences some qualitative data was also collected. This data was used to explain the results driven from the quantitative data.

Student feedback was collected by using a questionnaire where the primary focus was on perceived quality of the course. The basis of the questionnaire was an e-Learning Experience Questionnaire that is designed for a blended learning course (Ginns, & Ellis, 2007). This questionnaire was modified to fit better in our needs. The items concerning the quality of teaching and student interaction were left out of our questionnaire because we did not provide on-line tools to support these actions, and thus they did not belong to the area of our research. The items related to the on-line resources were shaped to concern specifically STACK exercises and the items concerning student management were expanded to concern the practical arrangements as a whole. Some items from other categories were also shaped to better suite the needs of the research at hand.

In our final questionnaire, we had six categories concerning the quality of the course: quality of STACK exercises, clarity of goals and standards, appropriateness of assessment, appropriateness of workload, practical arrangements and blended learning. Together the questions covered the quality aspects of Harvey and Knight (1996) as listed above. Most of the items of the questionnaire focused on quality as fitness for purpose, but many of these items can also be regarded to cover the quality as perfection or consistency or quality as value for money as well. There were also several items that concentrated on quality as transformation as we were highly interested in how the students feel about the changes in the course arrangements.

In addition, we asked the students general questions regarding their learning activities. They were partly inspired by the e-Learning Experience Questionnaire (Ginns, & Ellis, 2007); the questions concerning student interaction and engagement were rephrased to fit in the learning activities category. In addition, we took three items from the questionnaire of Kivelä (2002). These items dealed with the importance of different parts (lectures, STACK exercises and written exercises) of the course.

There were altogether thirty items concerning all the seven categories in the final questionnaire. Each item had five response possibilities on Likert scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree and 5 = strongly agree. In addition, there was an option for open comments. For background information we asked for the degree program and the starting year of the student. The questionnaire was conducted in Finnish.

Learning outcomes

The learning outcomes were studied using the final grades of the students as well as the information of how actively they had solved the exercises during the course. As the number of participants on the experimental course was relatively small, we could not organize a control group. For this reason the learning outcomes were compared with those of other courses.

The final grades were compared to the Discrete Mathematics course of 2009, which covered the same topics as the experimental course. The lecturer and assistant, however, were different, so the results are not reliable. We did not have the student activity data of this comparison group, so to compare the activity of students, we used the data of the Basic Course of Mathematics S1 from years 2007, 2008 and 2009. These activities have been studied previously in Rasila et al. (2010).

Results

Perceived quality of the course

The questionnaire was presented to the students on paper in connection with the second course exam and there were 24 responses for it. After the exam all the students who had signed up for the course had a chance to fill the questionnaire on-line if they had not done so in connection with the exam. In the end, we had 30 responses which is about half of the number of students who participated on the course. However, all the students did not respond to all questions, so the final number of responses was 28 - 30 depending on the item.

We will first consider the responses to the course quality questions. The categories are presented in the order of reliability, which is measured by Cronbach's alpha (Cronbach, 1951). With each category, we present the appropriate items and outline the responses in a table. In the tables we show the mean, the standard deviation (S.D.) and the number of answers in each response option for each item of the category in question. The items that are presented in a negative form are highlighted with *italic* font. As the result of each category, we report the mean of all responses to all items in the category, which is calculated after flipping the responses of the negative questions. The number of students is rather small, and we did not perform further statistical analysis.

We presented six items concerning the quality of STACK exercises (Table 1). The mean of all items in this category was 3,91, which tells that students were quite satisfied with the quality of STACK exercises ($\alpha = 0{,}81$). The open comments suggested that the feedback should have been more subtle. For example, one student wrote: “Often STACKs are too easy (especially when the hints tell straight the answer).”

Table 1. Items and responses focusing on quality of STACK exercises.

No.	Mean	S.D.	Disagree 1	2	3	4	Agree 5
4) The teacher's solutions of STACK exercises explained things well.	4,03	0,82	0	1	6	13	9
9) *I hardly read the teacher's solutions of STACK exercises.*	2,3	1,42	11	10	2	3	4
15) Overall, I am satisfied with the quality of STACK exercises.	4,4	0,67	0	0	3	12	15
17) *The automatic feedback from STACK exercises was not detailed enough.*	2,6	1,00	3	13	8	5	1
18) The automatic feedback from STACK exercises helped me to correct my incorrect answers.	4,07	0,91	1	0	5	14	10
26) The majority of STACK exercises were interesting.	3,87	0,82	1	0	6	18	5

Students' opinions on the appropriateness of workload were asked from the view of the on-line part of the course (Table 2). The mean of all items in this category was 4,5, so clearly the workload was appropriate ($\alpha = 0,73$).

Table 2. Items and responses focusing on appropriateness of workload.

No.	Mean	S.D.	Disagree 1	2	3	4	Agree 5
10) Overall, there was enough time to do the STACK exercises.	4,47	0,82	0	2	0	10	18
27) *Solving the STACK exercises was too laborious regarding the extent of the course.*	1,47	0,68	19	8	3	0	0

There were six items concerning the practical arrangements of the course (Table

3). The mean of all items in this category was 4,04, which tells that our practical arrangements were successful (α = 0,71). There were little problems using the STACK system and only few technical problems.

Table 3. Items and responses focusing on the practical arrangements.

No.	Mean	S.D.	Disagree 1	2	3	4	Agree 5
6) I was less anxious when taking the course exam than normally.	3,23	0,86	1	4	13	11	1
13) *It would have been better if there was only traditional written exercises on the course.*	1,57	0,68	15	14	0	1	0
14) I liked the weeks when we had only STACK exercises to do.	3,60	0,93	0	4	9	12	5
16) I benefited from the arrangement that you could return the exercises on-line.	4,33	0,80	0	1	3	11	15
19) There were little technical problems with STACK exercises.	4,27	0,98	0	3	2	9	16
25) *STACK system was difficult to use.*	1,60	0,77	16	11	2	1	0

The items focusing on blended learning regarded the connections between different parts of the course (Table 4). The mean of the items in this category was 3,85, which is less than in the other categories, but still very positive. From this we can deduce that the face-to-face and online parts of the course worked well together (α = 0,68).

Table 4. Items and responses focusing on the quality of blended learning.

No.	Mean	S.D.	Disagree 1	2	3	4	Agree 5
1) *STACK exercises did not relate to the things that lectures handled.*	1,76	1,09	16	8	2	2	1
2) I felt that I learned more on this course than I would normally on a mathematics course.	3,30	0,84	0	5	13	10	2
22) Solving STACK exercises helped me to learn the theory covered in lectures.	4,00	0,98	1	1	5	13	10

The assessment of the course was strongly based on the exercise points. Hence, the items concerning appropriateness of assessment dealed with the usefulness of solving the exercises (Table 5). The mean of all responses was 4,07. The internal consistency of this category, however, was insufficient ($\alpha = 0,4$) and the results cannot be concidered reliable.

Table 5. Items and responses focusing on appropriateness of assessment.

No.	Mean	S.D.	Disagree 1	2	3	4	Agree 5
5) Solving the exercises helped me to learn.	4,57	0,97	1	1	1	4	23
12) *The only thing that was really needed to solve the exercises was good memory.*	2,07	0,98	8	16	3	2	1
23) *The course could have been passed even if one didn't understand anything about the subject.*	2,77	1,22	3	13	6	4	4
24) Solving the course exercises prepared well for the course exam.	4,53	0,68	0	0	3	8	19

Experiences on clarity of goals and standards of the course were unraveled using two items (Table 6). The mean of all responses was 4,43. However, the conclusion cannot be regarded reliable (α = 0,38).

Table 6. Items and responses focusing on clarity of goals and standards.

No.	Mean	S.D.	Disagree 1	2	3	4	Agree 5
3) *The formation of the course grade was not motivated well enough.*	1,77	1,19	18	6	3	1	2
21) The basis for grading were clear.	4,63	0,72	0	1	1	6	22

Learning activities

In addition to the perceived quality of the course, we asked the students questions related to their learning practices. The goal here was to find out how the students studied during the course. Because the number of students was small, and it is not clear against what this data could be compared to, no statistical analysis was performed.

There were seven questions of students' learning activities (Table 7). We can see that most of the students solved STACK exercises mainly alone. Students mostly said that they studied during the whole course. Some students did confess to have guessed the answers of the STACK exercises, but fortunately most of them usually thought the exercises through. Although exercise points had greater meaning to the grade than normally, less than half of the students felt that they solved more exercises than regularly.

All the items concerning the importance of different parts of the course (28, 29 and 30) got a mean close to neutral. On average, students felt that written exercises were most important for learning and the responses for this item were also least fragmented. STACK exercises were on average held almost as important as written exercises, but the dispersion in students' opinions was clearly larger. The importance of lectures got the least mean score but it also divided opinions the most.

Table 7. Students' answers to questions concering their learning activities.

No.	Mean	S.D.	Disagree 1	2	3	4	Agree 5
7) I often solved STACK exercises together with friends.	2,13	1,63	18	3	2	1	6
8) Instead of studying at the last minute (just before the exam) I studied during the entire course.	3,53	1,31	3	4	5	10	8
11) *I often did not think through the STACK exercises, but guessed their solutions.*	1,93	0,94	12	10	6	2	0
20) I did more exercises on this course than I would normally do on a mathematics course.	3,27	1,34	4	4	9	6	4
28) Lectures were more important for learning than the other parts of the course.	2,68	1,19	5	7	11	2	3
29) STACK exercises were more important for learning than the other parts of the course.	3,17	1,02	2	5	11	10	2
30) Written exercises were more important for learning than the other parts of the course.	3,27	0,87	0	6	12	10	2

Learning outcomes

The grade distribution of the experimental course is illustrated in Figure 3. Of the 58 participants 49 were graded; the students who did not participate in neither of the exams and had solved less than 90 % of the exercises did not receive a grade. Although the option was given, there was not a single student who passed the course solely by doing exercises. Compared to the grade distribution of the same course on 2009, the percentage of grade 0 (fail) dropped from 34 % to 18 % and the percentage of grade 5 (highest) increased from 15 % to 45 %. Thus, the passing percentage among the graded students increased noticeably and almost half of the graded students received the highest grade.

The average percentages of solved exercises sorted according to the grade obtained are shown in Table 8. The results are compared to the outcomes of another engineering mathematics course Basic course of mathematics S1, that has also used both automatically assessed and traditional exercise assignments (Rasila et al., 2010). Based on the percentages, it seems that for students with grades 1, 2 and 3 there has been a significant increase in activity on the experimental course. The activity of non-graded students was low.

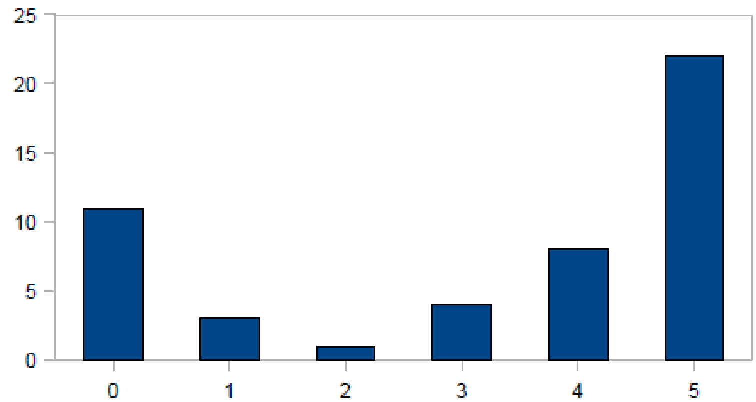

Figure 3. The grade distribution of Discrete Mathematics course on 2010.

Table 8. The average percentages of automatically assessed (above) and traditional (below) assignments solved by students with different grades.

	-	0	1	2	3	4	5
S1 2007		11,60	17,97	33,02	31,19	64,04	79,68
		3,78	7,77	20,19	9,40	26,84	61,61
S1 2008		13,20	23,62	36,55	49,56	65,60	74,89
		4,49	13,56	16,15	28,85	54,81	58,44
S1 2009		14,62	23,28	38,78	49,53	51,16	78,32
		3,77	10,00	29,20	50,48	68,22	92,48
DM 2010	13,95	10,05	34,71	76,63	68,87	63,43	91,32
	6,84	10,32	45,38	76,92	52,07	57,28	91,68

Discussion and Conclusions

We have found out that using e-assessment as a method of continuous formative assessment is a flexible way to answer to some of the common issues in using exercise assignments as a part of the assessment procedure. The feedback concerning the quality of the course suggests that the new arrangements did not result in too heavy workload on the students. The result is noteworthy because the data also shows that students actually worked very hard, although in general perceptions of workload do not seem to imply deep learning approaches (Lizzio et al., 2002). This can be explained by the increased motivation and meaningfulness resulting from the new arrangements. The other aspects of the quality studied also indicate a highly successful experiment, although the statistical data is inconclusive.

The general student feedback suggests positive development in learning strategies and orientations, but this conclusion cannot be proven within the scope of this study. The learning outcomes as measured by the grades were much better compared to the previous year's course. In general, the students appeared to be much more active on this course than on other engineering mathematics courses, but further studies are required because of insufficient comparison data.

The technology and practices described are also suitable for large scale teaching. They have been used on a larger engineering mathematics course Basic course of mathematics S3 on autumn 2010.

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