ENHANCING LEARNING AND TEACHING IN ENGINEERING MATHEMATICS WITH TECHNOLOGY

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Abstract

Nowadays, technology offers many tools to enhance learning and teaching. Students are familiar with using technological devices and digitalization is changing, for example, how we teach, study, connect and work. This paper introduces teaching experiments and the usage of technological tools in engineering mathematics courses Differential calculus and Integral calculus during the spring semesters of 2016 and 2017, at Tampere University of Applied Sciences. The aim on the courses was to enhance the learning outcomes by exploiting educational technology. The courses have utilized, among others, flipped classroom, STACK exercises, videos, online assessment and mathematical tools and software. These courses are compulsory for all engineering students. They are for the first year students and the experiment of the courses was carried out in the degree programmes in Construction engineering, Bioproduct and process engineering and in ICT engineering.

Keywords: engineering mathematics, mathematics learning, mathematics teaching, technological tools, flipped classroom, STACK exercises, videos, online assessment.

1 INTRODUCTION

The idea/need for the utilisation of technology in teaching and learning emerged from the perceptions that engineering students’ mathematics skills and knowledge have weakened, the study groups are large and heterogeneous, cohorts of incoming students vary (e.g. attitude to math, background), and resources for the teaching and preparation of teaching have decreased. [1], [2]

In the article Students, Computers and Learning by OECD [3] it was pointed out that achieving deep, conceptual and higher-order thinking demands intensive teacher-student interactions. Resources for teaching have been decreased and so there is less time for these teacher-student interactions. As a solution to this, the flipped classroom method was tested on the Differential calculus and Integral calculus courses. As a pedagogical model, flipped classroom has been described thus: it belongs to “a part of a larger pedagogical movement that overlaps with blended learning, inquiry-based learning, and other instructional approaches and tools that are meant to be flexible, active, and more engaging for students.” [4]. Flipping the classroom means that students will study the new theory (e.g. from videos, books or online materials) before the classes and then in-class there would be more time to do the exercises [5]. This leads to more time for teacher-student interactions in the classroom.

On the courses were tested short videos mainly as a resource for the study the new theory beforehand the classes. On these experimental courses were used short lecturer videos and the length of the video was less than 15 minutes. In this experiment, applications for the tablets, such as Explain Everything and ShowMe, and for the screencasting TechSmith Jing software, were used when producing the short video lectures. Videos contained examples, theory or combination of the two in a form a slides with the lecturer’s voice. There were also videos available to some exercises including hints or the solution for the exercise. Hsin and Cigas [6] and Kinnari-Korpela [7] has studied the use of similar kind of short video exercises with the good results.

In addition to the flipped classroom method and short videos, the courses wanted to utilize STACK (System for Teaching and Assessment using a Computer algebra Kernel) exercises as web-based assignments and as an assessment tool. STACK is a computer aided assessment system, which can be integrated into Moodle and as a Moodle plug-in it provides a question type for the Moodle quiz. Students’ answers to these STACK exercises are mathematical expressions (e.g. polynomial or matrix) and STACK checks students’ answers and gives feedback. The benefit of the STACK exercises is that you can randomize the elements in the exercises and this way it is possible to generate of a huge variety of versions of a single question. With these individualized exercises for the students, each student needs to solve their own exercises and they are not able to copy the solutions from each another. The first version of the STACK was published in 2005 and it is originally developed by Chris Sangwin. [8]
Rasila & al. [9] and Mäkelä & al. [10] have studied the use of STACK in basic mathematics courses. Rasila & al. observed the students gained better exam grades by doing more STACK and traditional problems. Mäkelä & al. observed that the students gained points from STACK exercises quite well due to the students kept solving the exercise until they got the correct answer. They also observed that the students were able to solve more challenging exercises quite well with the hints that are able to provide in STACK. They found the correlation between the points gathered in STACK exercises and the exam grades in a way student who gained better points from STACK achieved higher grades as well.

2 METHODOLOGY

An engineer student is required to use mathematical tools, software, calculations for solving problems in their engineering studies and also to communicate and present mathematical content [11]. This paper presents teaching experiments and enhance of technological tools in engineering mathematics courses Differential Calculus and Integral Calculus during the spring semesters of 2016 and 2017, at Tampere University of Applied Sciences (TAMK). Both courses are compulsory for all engineering students and the study was carried out in the degree programmes in Construction engineering, Bioproduct and process engineering and in ICT engineering. The courses are first-year spring semester courses (Differential calculus on 3rd period and Integral calculus on 4th period) and both are worth 3 ECTS-points.

On the courses TAMK's Moodle, virtual learning management system, was used for delivering learning materials and assignments. The use of flipped classroom method on the courses aims to increase the students' understanding of the theory and enables more time to do the exercises in-class. Different kind of e-learning methods and web-based assignments have become very popular in education [8]. On these courses a computer aided assessment system STACK was studied. Short videos were used on the courses to enhance students' learning and among others with the help of the videos, which students were able to watch with web browser through Moodle, students was guided to prepare to the classes. Also, in the article Students, Computers and Learning by OECD the videos were seen a good material for preparing to the classes [3]. This paper introduces the use of flipped classroom method and use of the STACK exercises in engineering mathematics courses Differential calculus and Integral calculus.

The aim on the courses was to enhance the learning outcomes by exploiting educational methods and technology. This study was especially interested in

- Do the STACK exercises enhance learning?
- Do the STACK exercises affect the grades?
- Are the short videos suitable preparation materials for the classes?

The flipped classroom method, short videos and STACK exercises were used as every-day tools throughout the courses. Students brought their laptops, tablets and/or mobile phones to the lessons. On the courses the students were able to use also, among others, symbolic calculator (mainly TI-Nspire CX CAS), Wolfram Alpha and Excel.

3 RESULTS

In the end of the Differential and Integral Calculus courses, the students were presented with a questionnaire to ascertain their opinions of the methods and technologies used in the course. The questionnaire was conducted electronically in 2016 and 2017.

The questionnaire contained five different sections. The first section contained questions about the student and their studies. The second section gathered data about STACK exercises on a 5-point Likert scale (1/Disagree, 2, 3 Don’t know, 4, 5/Agree). The third section included questions about the tools used, such as math software (Maple), symbolic calculator (TI-Nspire CX CAS), Excel, Wolfram Alpha on a 5-point Likert scale (1/Disagree, 2, 3 Don’t know, 4, 5/Agree). The fourth section related to the short videos and screencast (responses were yes or no) and the last section asked the students to rank the items in order of what is the best way to study the theory before the lessons (related to flipped classroom method where students study the theory parts in advance).
There were 158 responses to the questionnaires from two Differential calculus (from spring 2016 and 2017) courses and two Integral calculus courses (from spring 2016 and 2017). This chapter summarises the responses and gives a breakdown for each set of questions.

61% of the responses were from Construction engineering students, 14% from Bioproduct and process engineering students and 25% from ICT engineering students. From the responses, 54% related to Differential calculus and 46% to Integral calculus.

### 3.1 STACK exercises

The author of this article used the STACK exercises in Differential calculus course with two groups (Construction engineering and Bioproduct and process engineering) for the first time in 2016 with around 30 students/group. In the following year, 2017, the same course content was organized with two more groups (Construction engineering and ICT engineering) with around 30 students/group. None of the students had done these kinds of exercises before. STACK exercises were used as homework assignments and one part of the final exam of the course included STACK exercises. Homework assignments were designed in a way that the exercise gave instant feedback to the student, hints to the exercise and/or the solution of the exercise. Fig. 1 demonstrates one of this kind of STACK exercise that also includes the solution to the exercise.

![Figure 1. STACK exercise.](image)

E.g. in this exercise (only) the coefficient (here 7) was randomized element so this way it is possible to generate individualized exercises for the students.

In final exam of the courses, the first part of the exam was implemented with STACK exercises and the second part was a traditional pen and paper based exam. The first part of the exam was assessed on-line.

The final exam of the both of the courses (Differential calculus and Integral calculus) in years 2016 and 2017 included short STACK exercises. There were eight STACK exercises and the student was able to obtain 0 or 1 points from each exercise. The STACK exercises in the exams were the same in both years, except for the randomized elements. In 2016 the students were able to try to do the exercise once. The feedback from the students was that they felt it was technically difficult to give the input in the STACK exercise. The students were also asked to solve the exercises on paper, so checking the assignments revealed that the problem was not in the input but in the derivative itself or even more with managing algebraic simplifications. This issue, that students have major problems for instance with these basic algebraic simplifications, is mentioned in many studies [12], [13], [14].

In year 2017 a change was made in the STACK exam exercises so that the student was allowed to try each exercise twice. If the students did not get the exercise right with the first attempt, the STACK gave feedback that they could try again. The points from the exercise were: 1 point = correct answer at the first attempt, 0.5 points = correct answer at the second attempt, otherwise 0 points. This was done to make the students work with their errors. It was also good to make the students to pay attention to their accuracy and learning from their own errors. This system really helped students to
improve their scores as Table 1 shows (the average in 2017 was over 1.5 times better and median over two times better than in 2016 and standard deviation remained almost the same between years). Almost all students (81%) liked this system where they were able to try the exercise twice (only one student disagreed and the rest replied they did not know). Students also commented that opportunity to respond again reduces careless error. Table 1 also includes the key figures from pen and paper exercises. The pen and paper exercises were not the same in the following year but similar. The key figures shows that there were no major differences in the level of knowledge of the groups between years.

Table 1. Key figures from STACK exercises and pen and paper exercises from Differential calculus courses from years 2016 and 2017.

<table>
<thead>
<tr>
<th>Key figures</th>
<th>2016</th>
<th>2017</th>
<th>Key figures</th>
<th>2016</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>2.3</td>
<td>3.8</td>
<td>Average</td>
<td>8.5</td>
<td>9.2</td>
</tr>
<tr>
<td>Median</td>
<td>1.5</td>
<td>3.5</td>
<td>Median</td>
<td>8.3</td>
<td>9.0</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>2.1</td>
<td>2.5</td>
<td>Standard deviation</td>
<td>5.5</td>
<td>5.4</td>
</tr>
<tr>
<td>Min</td>
<td>0.0</td>
<td>0.0</td>
<td>Min</td>
<td>0.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Max</td>
<td>8.0</td>
<td>8.0</td>
<td>Max</td>
<td>21.5</td>
<td>21.5</td>
</tr>
<tr>
<td>n</td>
<td>63.0</td>
<td>63.0</td>
<td>n</td>
<td>63.0</td>
<td>63.0</td>
</tr>
</tbody>
</table>

The relation of the students’ STACK points and the grades were examined. It was found that there is a positive correlation between the STACK points and the grade. The Pearson linear correlation coefficient between STACK points and grades were 0.72 ($p < 3.49E-28$, n = 171). Also, the time which student spent in exam by doing the STACK exercises were examined but there was no correlation.

It was also noted that when the students had already completed STACK assignments during the Differential calculus course, the use of STACK exercises was much easier in the Integral calculus course. There were no big differences between the years in the points from the STACK exercises in the integral calculus course.

STACK exercises also received criticism from the students as Fig. 2 shows. Data included quite many “Don’t know” responses. This was the first time to all students when they came across these STACK exercises. By comparing the results from the earlier years where in the exam the STACK questions were made with pen and paper, the average was approximately 4 and standard deviation 2. As an observation, the students earned points from STACK exercises in year 2017 similarly than when doing those exercises with pen and paper.

Figure 2. Students’ opinions about the STACK exercises.
In free form questions, students gave feedback on the benefits and challenges of the STACK assignments. Many students listed for the benefits instant feedback, hints, solutions, web-based exercises and good way to learn. Other comments for the benefits were rapidity, new nice system, individualized exercises, meaningful to do, when you are good at math it is nice just to give the answer (no intermediate steps were required), forces a student to focus on the subject before lessons. For the challenges of the STACK exercises were listed: the entering of the answer, the accuracy of the answer, needs more rehearsal, merciless (you got 0 or half of the points if there is even minor simplification error), it takes too much time to write the answers in the right format.

While preparing the STACK exercises, it is possible to switch on the Auto-simplify but on these courses was seen that students have to be able to make the simplifications by themselves.

3.2 Videos and mathematical tools and software

With the help of the videos, the students who are not fluent in math are able to study the subject at their own pace. For all students, the use of videos is autonomous in the sense that it is up to the students themselves when and in what extent they use the videos.

During the courses the videos were mainly used as a homework assignments to watch the videos before or after lessons. In addition, during in-class sessions, the students were able to watch the video hints created for the some exercises.

96 % of the students who had watched the videos thought that the videos were useful for enhancing learning. Following question asked that should there be more videos on the courses and 79 % of the students preferred to have more videos. Free form question revealed that most of the students desired to have more videos among others from the solutions of the exercises with the intermediate results, theory and examples combinations and more videos about the challenging and applied exercises.

On the courses students were able to utilize symbolic calculator (mainly TI-Nspire CX CAS), Wolfram Alpha and Excel. Mathematical software Maple was used by the teacher to demonstrate mainly interactive visualisation and easy computations. Derivation and integration exercise assignments lead us sometimes to so time consuming computations that the students used symbolic calculator or Wolfram Alpha for the exercises. The responses to the questionnaire related to use of these tools and software were very favourable of the use of the equipment.

3.3 Flipped classroom

Nowadays there is less time for face-to-face support so for this reason, the flipped classroom model was used in the author’s classes. Students prepared for the classes in advance by reading books, notes, watching preparatory videos and doing online quizzes about the theory. In-classes there was more time to do the exercises and have interactive teaching sessions where there were more discussions between the students and the teacher.

It has been doubted that the students do not watch the assigned videos or other theory materials before classes [15]. At the beginning of the classes, electronic polls, created among others with the applications Polleverywhere or Google forms, have been used to become aware of the students’ knowledge of the theory. The questions in the polls have related to the topic at hand. Students have utilized their own electronic devices while replying to these real time questions. The right responses to the questions have been gone through instantly after the poll and this way the teacher has gained an instant understanding about the students’ knowledge of the theory at the beginning of the lessons. This way it has been possible to fill the gaps in theory parts, parts that the students had not understood or studied at home in advance.

Questionnaire contained a question that asked students to rank in order the best way to study theory parts before the classes. Videos were seen the best way to study the theory before the class (Table 2). This result is supported with the responses where 96 % of the students who had watched the videos thought that the videos were useful for enhancing learning.
Table 1. The best way to study theory before classes.

<table>
<thead>
<tr>
<th>Rank</th>
<th>The best way to study theory before classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Short videos</td>
</tr>
<tr>
<td>2</td>
<td>Moodle quiz</td>
</tr>
<tr>
<td>3</td>
<td>Book, lecture notes</td>
</tr>
<tr>
<td>4 (free form)</td>
<td>no suggestions</td>
</tr>
</tbody>
</table>

4 CONCLUSIONS

Different kind of e-learning tools and virtual environments are today’s education and with the help of these the students’ learning process can be assisted and varied. To summarize, the main benefits of flipped classroom model, STACK exercises and short videos are

- Instant feedback and web-based materials by using the STACK exercises
- Online assessment by STACK
- The use of automatic assessment by STACK allows individualisation of problem assignments for each student
- Videos were seen a good way to study theory
- Video solution for the exercises were seen very valuable
- With the help of the videos students are able to study the subject at their own pace
- It is up to the students themselves when and in what extent they use the videos
- Flipped classroom model provided more time to do exercises and involved more students in-class

Research questions about the use of STACK exercises to enhance learning and as an exam assignments, it was discovered that, there is a correlation between the points gained from the STACK exercises and the exam marks. Students who earned better points from STACK exercises achieved the highest grades as well. This in line with doing the exercises with pen and paper. In this study the STACK exercises in exam were split into smaller parts (a couple of points maximum). STACK exercises’ benefit as homework assignments is that the students get instant feedback from the exercises and with the help of the STACK exercises, the student’s learning process can be assisted.

Feedback from the students related to the short videos was very positive. Students were able to study the subject at their own pace and to pause the videos and replay them all over again. In addition, step by step solutions to the exercises including the explanations of lecturer were considered very valuable too. Moreover, the students were monitored by the quizzes. Quizzes allowed the teacher to monitor and adjust the pace and difficulty of the theory topics. From pedagogical point of view, STACK assignments and short videos enable learning personalization and the STACK exercises and short videos can be seen as promoting learning.

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REFERENCES


