INNOVATION MATHEMATICS PROJECT, BLENDED EDUCATION IN PRACTICE: A CASE STUDY AT DELFT UNIVERSITY OF TECHNOLOGY

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Abstract

All first-year students at Delft University of Technology (TU Delft) are required to take mathematics courses, but their motivation to participate in these courses is generally lower than their motivation for courses that belong to their main field of study. These lower levels of commitment often lead to lower results and weaker understanding of mathematical concepts, which in turn affect the rest of their studies. Two years ago, TU Delft introduced blended learning in the first-year interfaculty mathematics courses, in order to improve results, make more efficient use of teaching staff, facilitate the transfer of maths knowledge to other subjects and better connect with today's students. In this paper we provide an insight into the project, based on student and educator interviews, observations and surveys. Furthermore, we examine the impact of the flipped classroom model used in the project. Our findings suggest that the model could be a promising way of enhancing students' learning performance. The main results show that students have a more active learning experience, compared to the traditional setup of these courses, leading to more engagement and interaction. Furthermore, the project structure of the flipped maths courses provides opportunities for more scalable education. Based on our findings we provide recommendations, not just for this project but also for other course teams who are setting up similar projects in order to help them develop a model that best serves their education.

Keywords: flipped classroom, blended learning, maths education, higher education.

1 INTRODUCTION

In 2014, Delft University of Technology (TU Delft) initiated an innovation project, blending its interfaculty mathematics education in response to rising student numbers and developing technology. The university provides education to an increasing number of Bachelor and Master students and develops various mathematics courses for engineers (i.a. Calculus, Linear Algebra and Probability & Statistics), used as compulsory subjects for the more than three thousand freshman students.

As described by Vos [1] in an earlier paper with preliminary results, based on the first blended Calculus course, the goal of the project is fourfold: to improve the results, increase efficiency, transfer maths knowledge to other courses and better connect to today's students.

Vos concludes that commitment from both students and teachers is needed to make this new blended learning approach successful. In the table below several problems that needed to be addressed according to Vos are shown together with possible solutions (notions like 'pre-lecture' and 'FeedbackFruits' are explained in section 3).

Table 1: Problems arisen during pilot phase and possible solutions. (Based on Vos [1: p.9])

Problem	*Improvement*
Students don't watch pre-lecture	Video really replaces part of the content. Teachers were again instructed not to repeat pre-lecture content. Better connection between pre-lecture and lecture, by starting with quiz about or definition from pre-lecture.
Students don't make interactive (applet) exercises	More PR during lecture.
Teachers have difficulty with details or sequence of slide packs	In slide packs only definitions, graphs, pictures and quiz questions are included.
FeedbackFruits quizzes	Teachers are trained to say upfront: 'You have 2 minutes' or to

sometimes take too long	say: ‘Another 30 seconds before closing the question’.
Students may rely too much on the “help” they get in MyMathLab	In MyMathLab a few questions with help and a few without help, so students have to solve it themselves.

These improvements and more have been addressed in the meantime. The project is now well underway and it will continue as an iterative process. Results are available for the second run of Calculus and for Probability & Statistics and Linear Algebra.

In this paper we aim to report on the current phase of the project and relate this to recent ideas on what are considered good practices in education [2], such as active student participation, use of context, regular feedback on student progress, and emphasis on conceptual understanding. In the project a blended learning approach was used to achieve this.

Using an empirical methodology we regard the project as a case study as defined by Yin (cited in Yazan [3]) who points out that this method is particularly instrumental for program evaluation. We will not only relate the most recent findings but also address “how” and “why” questions that will enable us to evaluate and make recommendations for the next phase of the project in the last section.

In section 2 we present how the courses in the project are organised, and then continue in section 3 with an examination of the use of the above-mentioned educational principles in the maths courses. In section 4 we discuss the current phase of the project based on qualitative input from lecture observations, student and instructor interviews and further collected data. The final section discusses how our model could be a promising way of enhancing students’ learning experience and recommendations are made for further improvement of the blended learning experience for both students and instructors.

2 ORGANISATION OF THE COURSES IN THE PROJECT

2.1 Educational environment

All studies at the Delft University of Technology require a certain amount of mathematical knowledge and skill. The Delft Institute of Applied Mathematics (DIAM) facilitates this: all interfaculty mathematics educational activities are provided by DIAM. For example, Calculus for Civil Engineering students and Linear Algebra for Aerospace Engineering students.

DIAM is one of the six departments that together form the Electrical Engineering, Mathematics and Computer Science (EEMCS) faculty.

2.2 Courses and materials

A new blended approach (described in section 3.1) was first used during the pilot phase of the project (study year 2014-2015) to design four first-year mathematics courses, each for a specific faculty: Calculus 1 and 2 for Civil Engineering, Probability & Statistics for Electrical Engineering, and Linear Algebra for Aerospace Engineering. After the pilot phase, all four courses of the pilot were again taught using the new approach. Moreover, they were each ‘duplicated’ for another faculty: Calculus 1 and 2 for Mechanical Engineering, Probability & Statistics for Aerospace Engineering and Linear Algebra for Computer Science. During the first two years of the project, 32 instructors taught a total of 12 maths courses to over three thousand students using the new approach.

The project team now consists of a senior project manager, a junior project manager, eight instructors, an educational advisor, an e-learning developer and three student assistants. Each course has a responsible instructor. This instructor is responsible for the course schedule, enrolment, groups, grading, etc. The project team then develops the course materials and supports the responsible instructor during the course. The designed course is taught by a number of instructors. In order to create more personal contact between instructors and students, teaching groups consist of about 40 students per group. All courses are evaluated with the project team and the instructors who taught the course.

The courses are structured using a consistent flow and materials have been developed for the different types of learning activities by the members of the project team.

In the figures below an overview is shown of what the materials that are used look like and of how the lectures are structured[1]:

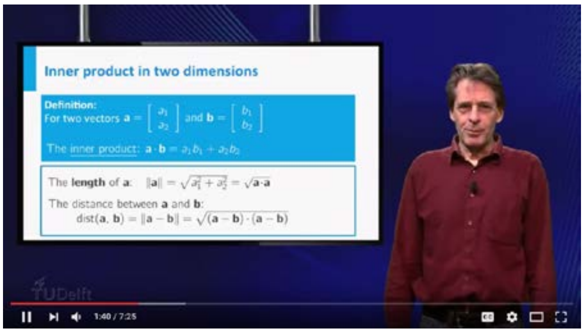

Figure 1: Screenshot of a video about Linear Algebra: https://youtu.be/c5z9bYFqOqM.

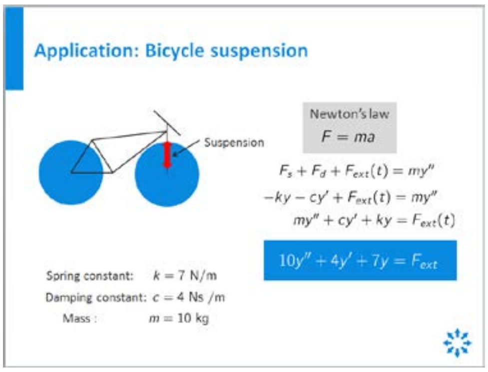

Figure 2: Example of a slide with an application of Differential Equations in Mechanical Engineering.

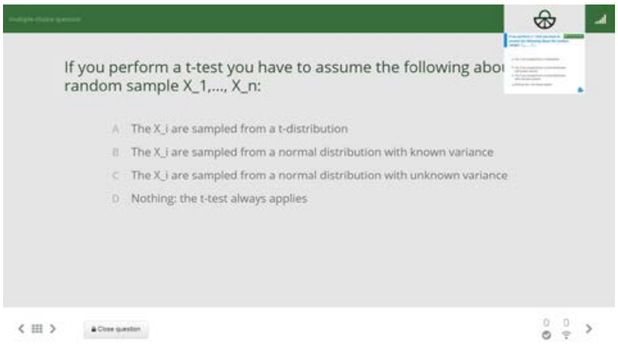

Figure 3: Screenshot of a question of the interactive quiz system FeedbackFruits.

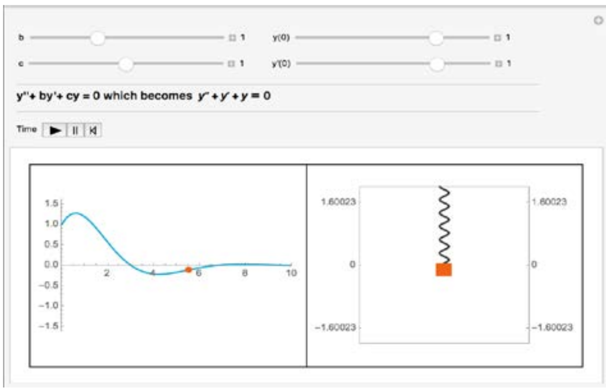

Figure 4: Example of an applet for Calculus.

[1] In this paper the words 'lecture' and 'session' are used intermittently. There is still a discussion within the project team as we feel 'lecture' often has a connotation of a lecturer talking to a group and does not convey the interactive student participation.

Fig. 5 and Fig. 6 show how these materials are embedded in a consistent structure in the online learning environment Blackboard.

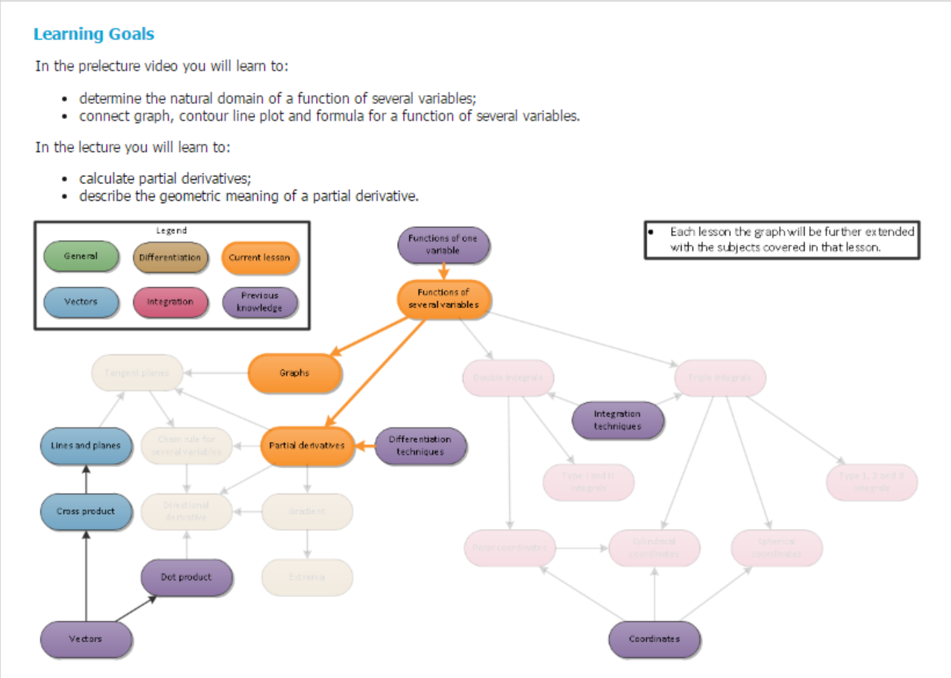

Figure 5: Example of part of a Blackboard page with the conceptual framework per lecture, displayed in an interactive concept map.

Each part in the structure is related to an activity and shows an indication of the time that a student can expect to spend on that activity. Moreover, an indication is given for when to do the activity: before or after the lecture. Students can choose preference to whether they study the lecture slides and book before and/or after the lecture.

Figure 6: Example of a Blackboard page (cont.) showing lecture materials and a post-lecture activity.

The exercises to be done during the lectures were selected from the book and the online exercises were selected from the online homework system MyMathLab by publisher Pearson. This selection was done by the responsible instructor.

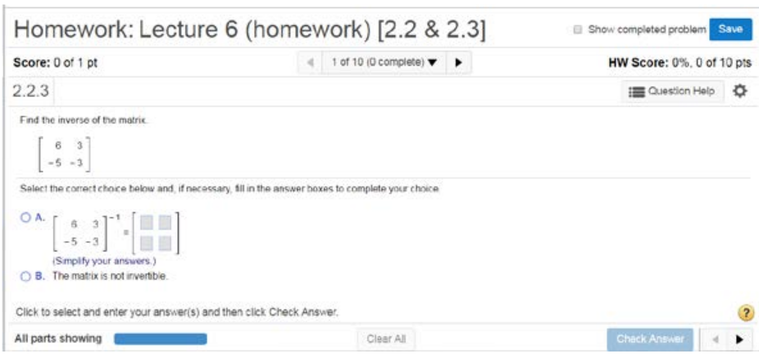

Figure 7: Example of an exercise in the online homework system MyMathLab.

3 APPLYING EDUCATIONAL PRINCIPLES THROUGH BLENDED APPROACH

To realise the goals of the project, the project has incorporated four educational principles based on research into good practice in education [2]: active participation in the teaching sessions, focus on conceptual understanding in the face-to-face contact, providing the students with adequate feedback on their performance, and using contextual problems to motivate the importance of maths in other fields of study [19]. To accommodate these educational principles, the project uses a blended learning approach.

3.1 The blended learning approach

There are many definitions of blended learning. Some argue that blended learning is simply combining traditional face-to-face learning and e-learning [4-5]. Bliuc, Goodyear and Ellis [6] extend this definition by adding that blended learning includes a systematic combination of face-to-face interaction combined with technology-mediated interaction between students, teachers and learning materials. Research comparing blended learning with traditional learning and e-learning has shown that blended learning can improve student academic performance [7-9].

The project team decided to use a specific form of blended learning, namely the flipped classroom. In the flipped classroom students watch recorded lectures in their own time and classroom time is used for more interactive sessions [10]. In this project, students prepare the face-to-face sessions at home, by watching video lectures and doing simple exercises. In this phase students activate their prior knowledge and acquire new knowledge. This knowledge and understanding is then tested during the face-to-face session using interactive questions using FeedbackFruits (see Fig. 3). Instructors also introduce new concepts, often based on contextual problems, and students work on problem-solving by doing exercises from the textbook. After the lecture, students process the new concepts by solving computer-aided problems (with automated feedback), exercises from the book and working with interactive applets. They continue the cycle by preparing for the next lecture. This blended learning cycle is depicted in the figure below.

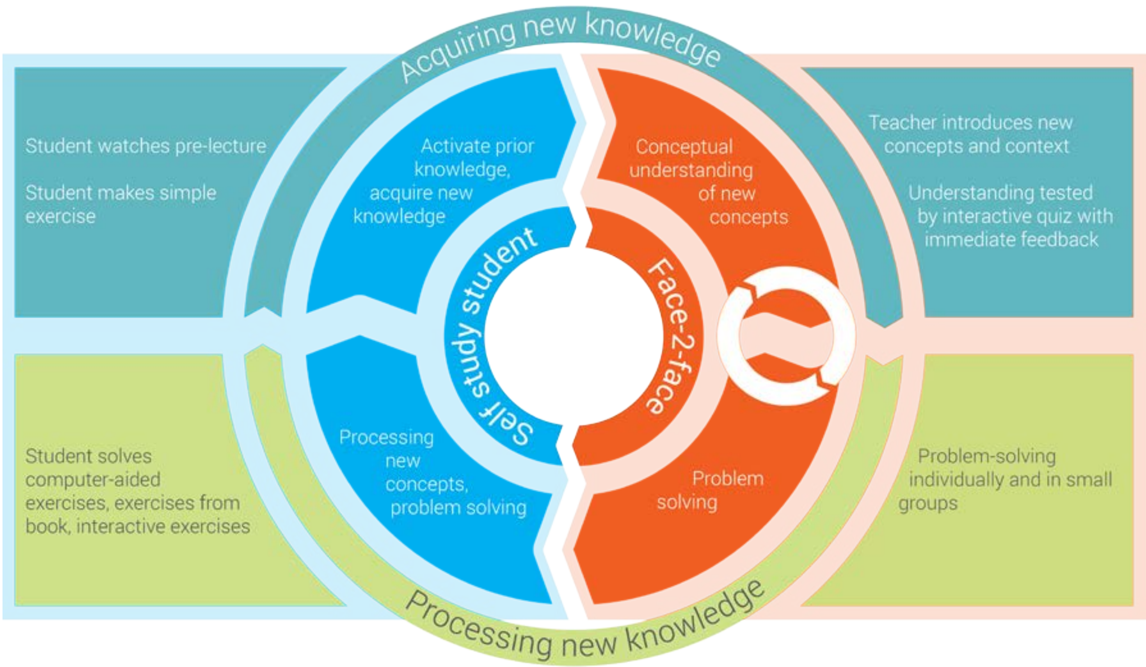

Figure 8: Blended learning cycle.

3.2 Educational principles

3.2.1 Activation

The first principle the project focussed on is stimulating active participation of students in every week of the course. The most basic form of active learning is to pause and let students discuss their notes [11]. Other examples of activities that can be used are quizzes, forums and peer-evaluation [12].

Different studies [13-14] show that active learning can improve retention and increase the exam results of the students.

These active learning principles are used both in the online as in the face-to-face sessions. Students are activated before and after the face-to-face sessions with interactive exercises in MyMathLab. The face-to-face sessions all contain interactive quizzes with the FeedbackFruits tool; the instructor shows the slide with a problem and students can vote for the right answer, using their own (mobile) device, followed by an interactive discussion of the correct and incorrect answers. The face-to-face sessions also have a fixed period for the students to apply the new knowledge and concepts, while they work independently or in small groups on exercises from the textbook with guidance by the instructor. Afterwards the difficult exercises are discussed with the whole group.

3.2.2 Conceptual understanding

The second principle of the project is to put emphasis on the conceptual understanding of the mathematical topics. A great deal has been written on the role of instruction in the construction of accurate conceptual knowledge by students. When designing the maths courses, it was taken into account that the designs should engage students' initial understanding. Also, it should promote construction of a factual knowledge foundation in the context of a conceptual framework, and encourage the development of metacognitive skills, as described by Bransford et al. [15].

Heibert (as cited in Rittle, Johnson and Sneider [16: p.3]) states that "Conceptual knowledge is characterized most clearly as knowledge that is rich in relationships." Bransford et al. [15: p.36] note that experts organise their knowledge around key concepts or 'big ideas' and that helping students acquire conceptual knowledge can also help students acquire more expert-like knowledge structures.

To accommodate the need for more conceptual knowledge, an interactive concept map (as shown in Fig. 5) was created for the blended maths courses. These concept maps contain all the important concepts of the course and show the relationships between the different concepts. In preparation of the face-to-face sessions, students can study the concept map and watch videos explaining new concepts. The face-to-face time is then used for more in-depth explanation, interactive quizzes, practice and examples. In this way students can acquire a conceptual understanding of the mathematical topics.

3.2.3 Feedback

Feedback is one of the most powerful influencers on learning and achievement [17]. Therefore, feedback is one of the four principles of the project. The aim is to give students regular feedback on their progress. Hattie describes [18] that one of the most effective forms of feedback is to give cues or reinforcements to learners by the means of audio, video or computer-assisted instructional feedback.

This type of feedback is used in different phases of the course design. After watching the pre-lecture videos and after the face-to-face session students do computer-aided exercises in the MyMathLab environment (see Fig. 7). The online homework system MyMathLab helps students to maintain regular practice of the course content with instant feedback. Students are expected to do weekly assignments which can quantitatively or qualitatively influence the final grade. This environment gives feedback to students on their performance and also has a functionality named 'help me solve this', which provides the students with cues and tips.

During the face-to-face sessions, students receive immediate feedback by doing the interactive FeedbackFruits quizzes. They also receive personal feedback from the instructor during the time spent for problem-solving.

3.2.4 Contextual problems

The fourth principle is to use contextual problems related to the specific field of study. This is based on the idea mentioned by Pashler et al. [19: p.16] that "When teaching students about an abstract principle or skill, such as a mathematical function, teachers should connect those abstract ideas to relevant concrete representations and situations, making sure to highlight the relevant features across all forms of the representation of the function". According to Rawson et al. [20: p.486], concrete examples can help to understand abstract concepts. So, using examples is important for teaching abstract concepts.

Both the online videos and the face-to-face sessions include contextual problems. The instructors are provided with a slide pack, in which each lecture consists of one or more contextual problems (for an example, see Fig. 2).

4 FINDINGS AND RESULTS

In this paper the focus is on qualitative data collected from lecture observations, student and instructor interviews and surveys, and evaluation meetings. The lecture observations were meant to gain a wider understanding of how the blended principles were applied in the face-to-face sessions. The interviews and evaluation meetings provide an insight into the student and instructor experience with the blended structure.

The results are discussed below, based on the four principles for good educational practice as described in the previous section. We incorporate some quantitative data such as the results from student and instructor surveys. The results of examinations are not discussed at this stage of the project; it is too early to use these results to base conclusions on the impact of the project on the TU Delft maths education. Table 2 gives a breakdown of the data collected.

Table 2: Breakdown of the collected data.

Courses	12
Students	Approximately 3000
Instructors	32
Lecture observations and interviews	26 (of which 6 peer-to-peer)
Surveys for instructor response	3 completed by 15 instructors
Surveys for student response	8 completed by approx. 1250 students
Evaluation meetings with instructors	11 with 25 instructors
Evaluation meetings with students	2 with 13 students

4.1 Activation

Students reported that they think they learn more in these blended courses compared to courses with a more ‘old-fashioned’ organisation and that they are more active. They find the structure of the online learning environment (see Fig. 5 and Fig. 6) very clear and well-organised; it provides a comfortable workflow.

Some students prepare the lecture by studying the pre-lecture video, while others find it difficult to get in the workflow of preparing for a lecture. Therefore, not all students make it a habit to study the pre-lecture videos. In general however, students feel that the video lectures help them prepare for the lectures and for the exams. Instructors report that they still feel at a loss sometimes when they notice that not all students have prepared for the lectures. Should they explain what was in the video again or just continue with their lecture? The advice they are given is to just continue, so students will feel they need to prepare.

During the lecture observations it was clear that the time instructors talk and explain is less than in more traditional maths lectures. Students are activated at different moments during the face-to-face session by solving FeedbackFruits quizzes and working on problems from the textbook. However, this can take a lot of time and faster students have sometimes already answered a FeedbackFruits question when the slower students are still coming up with an answer. Instructors were advised to set a specific time and not to wait for everyone to be finished to keep the pace during the lecture. It was also noted that some instructors tend to explain answers, even though most students had answered the question correctly.

Many instructors do not really foster collaboration between students. They do not mind students working together, but they do not use strategies for students to collaborate more. Students mostly work individually and most instructors do not vary the use of teaching methods other than what is suggested in the slides developed by the project team.

Not all instructors are comfortable with this new way of teaching. For example, some mention they experience difficulty switching between the PowerPoint presentation and the interactive quiz system FeedbackFruits. Also, the slide packs, provided for each lecture, cause some to feel that they can no longer give a personal touch to their lecture. This may reflect on the experience and therefore activation of the students, although all in all students still state they are more active than in other courses.

4.2 Conceptual understanding

The flipped learning structure enabled the instructors to spend more time on building on the preliminary knowledge the students had gained from watching the pre-lecture videos. More time could be spent explaining and relating concepts and have students apply the new knowledge during the problem-solving part of the face-to-face session. Most instructors considered this to be a clear benefit of the blended approach.

Students appreciate the way the concept map shows the relations between the different topics and mentioned that they would prefer if instructors would refer to these more during the lectures.

4.3 Feedback

Many students claimed the instant feedback in MyMathLab and the interactive FeedbackFruits quizzes helped them understand where they still had difficulties and what they still needed to practice, although some did not participate because they did not feel it benefitted them.

Participation in MyMathLab started high (about 85%). For courses with deadlines and restrictions on the help options, participation gradually decreased to approximately 20%. Many students prefer the MyMathLab exercises over the textbook exercises. However, if they missed many deadlines and/or the designed bonus scheme – based on a certain effort in MyMathLab – could not be met, students would abandon their efforts to do the online exercises. For courses without deadlines and restrictions, participation started at and maintained above 90%. In that case however, some students would refresh the exercises until they found one they could easily do. So, higher participation did not necessarily imply a better learning experience.

At the beginning of a course, FeedbackFruits participation was mostly high (approximately 80%). During the course, when students were more used to it, participation decreased to about 50%. Some students would also give each other feedback while answering questions together.

In general, students appreciate the small class size, for they allow a personal approach and give the possibility to ask questions. During the problem-solving sessions, instructors would provide individual feedback. Students appreciate this time spent on exercises during lectures. Some instructors use the time for exercises for more explanation; however, most students prefer to have time to work on problem-solving with support of the instructor.

4.4 Contextual problems

Many students mentioned that they value the added context during the lectures. The instructors explain how the just learned mathematics can be used in an application in the field of their studies. In this way students felt that what they learn in the maths courses can be transferred to other courses in their field of study.

Students would also like to see more context examples that add to the theoretical explanations during the lectures. Instructors sometimes skip the context examples in the slides due to lack of time for explanation of the maths concepts. Moreover, students feel more can be gained from adding context to the lectures. For instance, some examples do not appear realistic or they are too difficult.

Some instructors mentioned that they do not feel comfortable using these context examples, as they are not part of their own field of study. They are used to teaching mathematics using theoretical examples.

5 CONCLUSIONS AND RECOMMENDATIONS

Our findings suggest that the blended approach in our model could be a promising way of enhancing students' learning experience. During lecture observations we noted that instruction is more activating, compared to the more traditional organisation of these courses, leading to more student engagement and interaction. This is also confirmed in student surveys and interviews with students and instructors.

It is also clear from the observations and interviews that behavioural change is difficult. Both students and instructors need to change the way they work if this approach is to be a success. Students should be explicitly instructed on how and when to prepare lectures and practice the content. Instructors need to be inspired and sometimes motivated to change the way they teach. Regular evaluations and deliberation are needed to accommodate the needs and worries of the instructors.

On the other hand, improvements have been made based on the evaluations in the subsequent runs of the courses. For example, some of the courses now have practice exercises following the pre-lecture videos. Instructors who have been involved in more of the blended courses are becoming accustomed to the new approach and they appreciate the time that is freed up by the pre-lecture videos to spend on more in-depth class time. Likewise, some students who have also done more blended courses are used to the clear and consistent course structure and they feel they come to class more prepared when they have done the pre-lecture activities.

A great benefit of a quiz system such as FeedbackFruits is the fact that the instructors can directly see whether the subject that they just explained was understood by the students. Subsequently they can adjust their lecture according to the results. Another advantage is that FeedbackFruits works on any laptop, tablet or smartphone. Therefore, no clicker devices are needed. The fact that most students work on their smartphones is at the same time a disadvantage, as they are easily tempted to be distracted by other activities on their phone, such as WhatsApp and Facebook.

Some recommendations for further improvements and for further research:

- The integration between the online and face-to-face sessions should be a constant focus for the instructors, for example by regularly referring to what has been done as preparation at home.
- Ongoing evaluations that lead to continuous adaptations of the courses will be beneficial for improvement.
- The pre-lecture videos could be made more interactive by adding quiz questions to the video.
- Naming the different parts of the work flow still needs attention. If all are integrated parts that are equally important, it does not seem wise to call some parts pre- or post-lecture activities. Kristina Edstrom [21] states that renaming can sometimes make a lot of difference in how students experience something.
- For the purpose of data analysis, it would be a great addition if FeedbackFruits would register the students by student number instead of any name they choose (as it is now), and if it would register whether the students' answers are correct. If that data were available, the correlation between FeedbackFruits participation and for example exam grades could be calculated.
- Workshops for instructors should be organized on a regular basis on how they can implement the new learning strategies and tools, such as the interactive quizzes, peer instruction, the use of the concept maps and the problem-solving exercises. Not all instructors are familiar with these didactical approaches and they are sometimes insecure to use them in their face-to-face sessions.
- Data on examination results collected over the coming years will enable a quantitative comparison to see whether results improve. However, it will be more than just grades that improve. Research should also be done in whether students transfer the skills they learn in these courses to their other courses more than before.

In the end, however, "it is the teacher's responsibility to create the conditions in which understanding is possible and the student's responsibility to take advantage of that." [22: p.1].

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