FLIPPED MATH, LESSONS LEARNED FROM A PILOT AT MECHANICAL ENGINEERING

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ABSTRACT

At the University of Twente, all bachelor programme curricula are organised as thematic modules with a project and several courses. The courses offer students knowledge and skills that can be integrated and applied to design a solution for the problem presented to them in the project. A 'just-too-late' teaching model is applied, meaning that knowledge is offered to students a while after they encounter challenges and problems in the project, so they will first try to come up with their own solutions. For most courses this model is working well. For the math courses this is somewhat more difficult, partly because it is a general course offered to all engineering and science programmes at the same time.

To create more flexibility in the timing of the math courses and to get students to engage in the subject matter earlier and more actively, a flipped classroom setting was designed including diagnostic tests and repair sessions. A pilot is conducted to test this setting in which 102 students participated.

The pilot was evaluated by classroom observations, interviews, surveys at different moments during the course, analysis of Blackboard log files and a panel discussion. After the first weeks, participation during lectures and diagnostic tests dropped dramatically. The pass rate of the course was 66%, compared to 80% in previous years. Evaluation results showed that a substantial part of the students was not actively involved in the self-study activities from the beginning of the course and that active class participation dropped further during the module. Also some positive effects were reported by students engaging more actively with the subject matter and gaining better insight.

A set of recommendations was made for improvement of the flipped classroom setup focussing on stimulating and retaining active involvement of students.

KEYWORDS

Flipped classroom, Math Education, Active Learning, Student Engagement, Standards 2, 3, 8 and 10.

INTRODUCTION

The University of Twente is research intensive university with approximately 9.500 students and 3000 staff members (support and academic). While the university is known as a technical university and a member of the 3TU federation (http://www.3tu.nl), non- technical programmes like communication science and business administration are also part of the university's offer. Between 2010 and 2015 the three technical universities in The Netherlands have engaged in a major bachelor innovation (Gommer, Klaassen & Brans, 2015). The University of Twente chose to implement a new educational concept bearing a large resemblance to the CDIO concept; the Twente Educational Model (TEM, 2016). Following the educational model of the engineering programmes, where thematic project education has been the leading educational model for many years, all programmes were divided into thematic modules of 15 ECTS (1 quartile). The core of every module is a design or research project where students work in groups to solve a complex problem. Theoretical courses as well as practical workshops are offered to students to provide them with the knowledge and skills needed to approach the problem. A 'just-too-late' teaching model is applied, meaning that knowledge is offered to students after they encounter challenges and problems in the project, so they will first try to come up with their own solutions.

The aim is to make all modules 'Student Driven', meaning that the focus is on active learning methods and on enabling the student to be responsible for his or her own learning process by offering choices in content as well as working methods and stimulating active study behaviour. At mechanical engineering explicit attention is paid in the first two modules on study skills and reflection to support students in their development towards self-directed learners.

For most courses this thematic approach with 'just too late teaching' works quite well. The theory is integrated into the project stimulating the students to actively engage in the course content when it's needed to contribute to the design or the research project.

For the math courses this is somewhat more difficult. One reason is that math is a general subject offering students the basic skills for design as well as research, but the direct application to the project is not always clear. Also, in the TEM educational model, math education is included as a general learning theme with courses offered to all engineering and science programmes at the same time. However this being very efficient, the result is that there is not always a match between the project and the math topics covered in the same module. In some cases the math content offered differs from the math that is needed to complete the project. In other cases there is a match between content and project, but there is a mismatch in timing (e.g. topics are offered in the math course when the project-phase in which they are needed has already ended).

At the mechanical engineering programme, the problems of non-matching content and timing were experienced in several modules. In some cases extra math explanation was needed for students to complete the project. Also, a tendency exists to postpone studying math content until right before the exam because there is no stimulant coming from the project to dive into the material earlier.

To create more flexibility in the timing of the math courses and to get students to engage in the subject matter earlier and more actively, a flipped classroom setting (De Boer and Winnips, 2015) was designed including diagnostic tests and repair sessions. The question we aim to answer in this paper is:

Does this flipped classroom set-up help students to engage in the subject more actively and obtain a better understanding of the math subject?

The method section describes the flipped classroom set-up as well as the methods and instruments used to evaluate the pilot. In the results section student and teacher experiences and pass rates are reported.
In the final section, a conclusion is formulated, supplemented with recommendations for improvement of the flipped math set-up.

METHOD

Set-up of the pilot

The pilot took place during the math course in the fourth quartile of the first year mechanical engineering programme. The thought behind this was that if successful, the flipped classroom approach could be more broadly implemented with the new students starting the programme in September.

In its original set-up, the math course has a duration of 6 weeks with one lecture a week for all science and engineering students and a weekly tutorial at programme level. Students are assessed by means of two exams, one half-way through and one at the end of the course. Both exams deal with different topics. A digital learning environment (Blackboard) is used to provide students with the necessary information. 'MyLabsPlus' (from Pearson publishers) can be used by students to practice with the course content.

In the new set-up (see figure 1), students do not attend math lectures, but instead work at home, orienting on this week's topics, supported by learning materials placed on Blackboard. Every week, the lecturer places a structured document on Blackboard for every topic that is covered during that particular week. This document contains an explanation of the topic, practice assignments and (where possible) references to the math book and to short instructional videos on YouTube where topics are explained in more detail or from a different angle.

By following the instructions in the self-study document, students could prepare for the different topics independently. Any questions the student might have on the topic could be taken to the question hour on Wednesday morning. The aim of this meeting was to give students an active role and give them the opportunity to learn from each other and from the questions and explanations from fellow students.

The question hour was followed by a tutorial where students work on assignments in the book with supervision of a lecturer from the math department.

Instead of the summative in-between tests in the original version, a diagnostic test is scheduled on Thursday's. By participating, students would receive feedback on their progress and understanding of the subject matter and also get acquainted with the way of working towards the solution of the math problems. Right afterwards, the diagnostic test was discussed by the lecturer in dialogue with the students. The week was concluded with a so called 'repair tutorial' where students could work on the topics that they didn't do well on during the diagnostic test and receive some extra explanation from the lecturer.

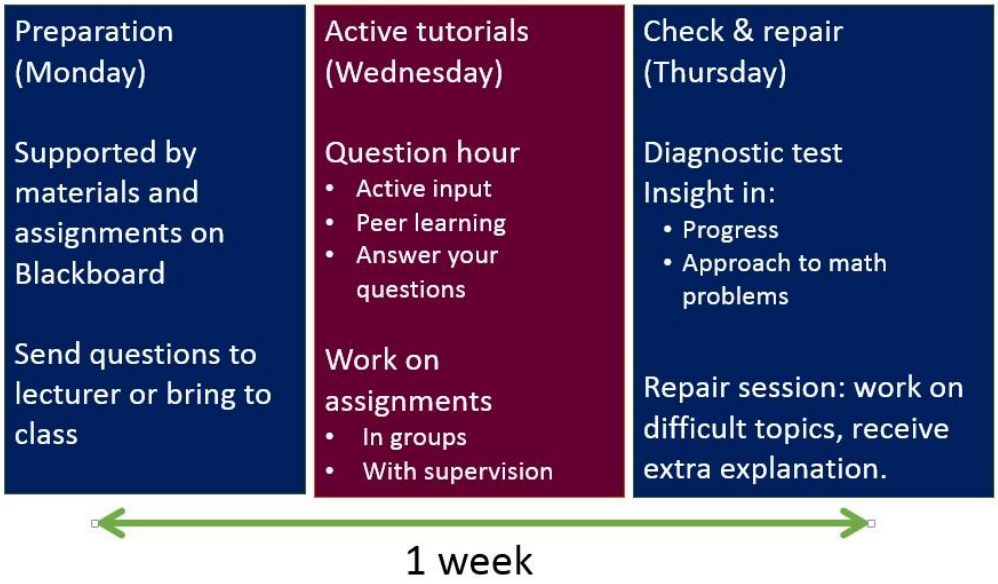

Figure 1. Weekly structure as presented to students

Evaluation of the pilot

102 students participated in the pilot setting. The pilot was evaluated in different ways. First of all, an educational advisor from the centre of expertise in learning and teaching attended several different meetings of the math course to observe attendance and active participation of students, the amount of interaction in the classroom and teacher behaviour. Information from lecturers was collected through evaluative discussion and email to determine their experiences with the flipped-classroom set-up and students' reactions to it.

At three times during the course, a survey was conducted with students; at the beginning of the module during the first meeting, half way and at the end of the course. The survey contained both open ended as well as closed questions about attendance to and appreciation of different components of the flipped classroom setup, expectations about the course and the degree of difficulty, etc.

In Blackboard, log files were kept of the frequency and timing of student access to the materials for preparation of the topics. These log files were compared to students' test results.
After the course a panel evaluation was held with four students to elaborate on the survey results and discuss their experiences with the flipped classroom setup.

RESULTS

Observations and attendance

What was noticed during the first question hour is, that response from students was low, even though it was clearly announced that the lecture would be given based on questions coming from the students. After putting in some effort, the lecturer managed to attain some interaction with students and to get some students to demonstrate solving a problem in front of the classroom, but this remained difficult, also during later question hours.

Attendance during the question hour and tutorials was 65% during the first three weeks, dropping to 30% during the last week. Attendance at the diagnostic test was low from the beginning (approximately 35% during the first three weeks). Halfway the course the diagnostic test was moved to the end of the week (after the repair tutorial) because students indicated that they needed more time to prepare for the test and practice with the subject matter. Despite this switch attendance continued to drop to only 3 students attending the last test.

Students indicated that exams from parallel courses and exam resits from the previous period interfered with the math course, a possible cause for the attendance-drop during the last three weeks.

Blackboard log files

The decline in attendance was not reflected in the amount of activity on the Blackboard page of the Math course. When looking at the amount of 'views' of the relevant Blackboard pages, students who are active on Blackboard remain active during the second half of the course with an increase of activity during the last week before the math exam. What is not visible however, is if students are still working according to schedule or if they are falling behind. Also, it is not visible if the nature of the activities changes. Are students still working on the practice assignments or do they just read through the document?

When the amount of activity on blackboard is compared to the final course grade, a positive correlation is found of 0.23, sig < 0.05 (Figure 2). The average number of views of the math folder on Blackboard of students with an insufficient final grade (≤ 5.4) is 99. The average number of hits of students with a sufficient grade (≥ 5.5) is 169.

Figure 2. Number of views of the main folder on Blackboard compared to final grade

Evaluation

During the course, three surveys were conducted at the start, halfway and at the end of the math course. The number of respondents declined from 64 filling in the first survey to 30 filling in the third one (parallel to the decline of attendance during the lectures).

Start survey

65% of the student population participated in the start survey. The basic attitude towards math and the confidence in their math skills is on average high: 80% of the students say they

generally are good in math. 67% say they like doing math. Expectations on how much fun the course will be are not very high. Average score (on a scale from one to 10) is a 5.9.
When asked what they expect not to like about the course, 16% comments on the expected workload and time investment the new setup will ask for. 13% comments on the flipped classroom setup in general.

On average students expect to obtain a 6.6 as a final grade for the course. Only 4 students expect an insufficient grade.

Midterm survey

Fifty percent of the students participated in the survey halfway the course. Looking at attendance, the tutorial on Wednesday had the highest attendance rate. 63% of the respondents indicate that they have attended all three tutorials. The diagnostic test on Thursday had the lowest attendance. Only 25% of the respondents indicated that they participated in all three tests.

The majority (74%) of the respondents indicated that they did work on the self-study assignments; 39% of the respondents made all assignments, 35% did part of the assignments. Students that did not do the assignments indicated that they preferred the assignments at the tutorials or that they did not need the self-study assignments to understand the subject matter. Most students (63%) did not use the instructional videos. The main reason was that students did not need the videos to understand the subject matter.

Some statements were presented to students about the usefulness of the different components of the new setup and about the flipped classroom concept as a whole.

Table 1. Statements on usefulness of the flipped classroom concept

Statement	**Negative (%)**	**Neutral (%)**	**Positive (%)**
The text in the self-study documents were clear	17	20	63
The assignments helped me to understand the subject matter	20	13	67
The videos helped me to understand the subject matter	25	45	30
The question hour on Wednesday was useful	13	25	62
The tutorial on Wednesday was useful	4	11	85
The diagnostic test gives me a good insight in the subject matter	15	25	60
The discussion of the d-test is useful	11	23	66
The repair tutorial is useful	25	30	45
I like the flipped classroom setup	45	22	33
The new setup help me more than the traditional setup	40	33	27
I would like to have more math courses offered in this setup	42	27	31
I would like to follow other courses besides math in this setup too	56	31	13

Noticeable is that most students are positive about the separate components of the new setup (with the exception of the videos), but that the flipped classroom setup as a whole is

appreciated much less. What also stands out is that two third of the students is positive about the usefulness of the diagnostic test and the discussion while this was the component with the lowest attendance (25% attending all three tests).

Students were asked what they liked about the new math course setup. Most mentioned answers were:
- Being more actively engaged in the subject matter (24%)
- Gaining more insight in the subject matter (20%)
- Working independently / freedom to work at your own pace (20%)

These correspond with the aims of the pilot as described in the introduction paragraph.
What students did not like about the new setup was:
- Having to do / find out too much by yourself (24%)
- Workload, pressure to keep up with the pace (17%)
- Absence of lectures (14%)

During the oral discussion after the evaluation students added that they did not like to have the diagnostic test before the second tutorial because this gave them too little time to work on and master the subject matter. After the midterm evaluation this was altered.

End survey

Thirty students participated in the survey at the end of the course (before the exam). As an answer to the question what was learned during the course, most students (76%) give a math content-related answer, 24% of the students say they have learned something about planning and working independently.

When students are asked what they like about the course, 36% give a content-related answer. Half of the respondents mentioned the new setup or an element from the new setup.
As an answer to what they did not like, 43% of the students mentioned the new setup, 26% specifically mentioned the absence of summative in-between tests.

The expectation regarding the grade that will be obtained has remained the same (6.6 average). Only two students expect to obtain an insufficient mark. This strongly disagrees with the actual pass rate.

Pass rates

In week 4 a test exam was offered to students, covering the first part of the course content. 56 students participated in this test. Only 9 students obtained a sufficient mark. The lecturers indicated that students did not seem worried about these results when they were announced in class. Their impression was that students did not take the test exam very seriously and that many students were not on schedule studying the subject matter.

After the math course, the summative exam took place, covering all course content. At the first attempt 48 mechanical engineering students obtained a sufficient grade (≥ 5.5). This sets the pass rate to 47%. At other programmes, the pass rate was considerably higher (60%) while usually mechanical engineering students have comparable to slightly higher math scores than students from other programmes. After the resit, the pass rate rose to 66%, compared to a pass rate of 80% last year.

Panel discussion

A discussion was organized with four students. Final grades of these students varied from 4.5 to 6.8 on a 10-point scale. Two students attended all types of lectures, two only attended the tutorials. Two students indicated that they made all practice assignments on Blackboard. One student only looked at the documents but didn't make the assignments. One student tried to make the practice assignments but did not always succeed in finishing them before the tutorial. About the question hour students indicated having low expectations of the amount of input and interaction that would come from fellow students and therefore they questioned its usefulness. Suggestions for improvement are: smaller groups (30 – 40 students), give students a more active role, less open setup to help students to start up, look at the pdf's together.

The video materials were not used a lot because the subject matter was clear to these students. What students liked about the new setup was the independence, the weekly documents on blackboard that made them dig deeper into the subject matter and the diagnostic tests.

The main point for improvement mentioned was that there was too little time to finish the weekly practice assignments. The documents on Blackboard were appreciated but cost a lot of time to work through. Less subjects in the weekly documents would appeal more to students.
About the low attendance at the diagnostic tests the panel students think this is caused by the exams from other courses on Friday and students feeling it's not useful to do the diagnostic test when they are behind on studying the subject matter.

When asked about the low percentage of students wanting this setup for other courses, the panel students indicate that they have a hard time imagining how other courses besides math could be carried out in a flipped classroom setting.

Finally, students reported to be surprised about the final grades. They did not attend the last diagnostic tests but had a good feeling about their mastery of the subject matter and expected a higher grade.

CONCLUSION AND RECOMMENDATIONS

Conclusion and discussion

Looking at the pass rates of the course we can safely conclude that the desired end result was nog yet attained. What was aimed at was, that the with the new flipped classroom approach students would engage in the subject matter more actively and dig deeper into the different topics to gain more insight in the subject matter.

Final grades show us that this is not the case. Pass rated are fourteen percent lower than prior years. Other programmes that followed the traditional setup with the same exam do not show this decline.

However, it also seems too early to write off this approach as a complete failure. Certainly during the first half of the course some of the students reported the effect that we hoped to see with all students. Students opened their books, searched actively for answers and indicated a better understanding of the subject matter.
What was disappointing was the lack of active participation during the question hours and the declining attendance during the tutorials and the diagnostic tests. Partly, this could be

attributed to students not being used to this independent approach to learning and weren't able to make the turn during the fourth quartile. The fourth quartile is typically a quartile in which motivation and student effort somewhat sinks in. This new approach based on self-responsibility was not taken up very well.

Noticeable was that attendance at the tutorials and the diagnostic tests dropped dramatically during the second half of the course, at the same moment the other courses in the module started their formal tests. A possible explanation is that a large part of the students stayed away because these assessments were prioritized over the diagnostic tests from the math course. Once fallen behind on the sturdy pace of the math course, it is hard to catch up again. Overestimation of oneself also seems to play a role here. Even after the very bad results of the first test exam, attendance at lectures and diagnostic tests did not improve as might be expected, but instead further declined.

Looking at literature, this effect is seen more often when flipped classroom settings are implemented (De Boer and Winnips, 2015). Students that do participate actively seem to benefit from the new approach, but the real challenge is to get (and to keep) students on board without imposing all kinds of regulations on students contradicting the self-responsible approach to learning we hope to evoke.

Recommendations for improvement

To improve participation in this flipped classroom setting without introducing measures like obligatory attendance or summative assessment or classroom preparation, several things can be done.

Integrated approach

In this pilot, the math course was given in a new setup with only diagnostic in-between testing. Other courses within the same module however, did not abandon their in-between summative tests causing unfair competition for the math course. Especially on Thursdays, students tended to stay away, because most summative tests were scheduled on Fridays. An integrated approach where all courses running parallel within the same period follow the same approach with regard to self-responsibility and in-between assessments will prevent courses from 'competing' with each other for student effort.

Ideally, an educational approach asking from students to work independently and take up responsibility for their own learning should not be part of just one or two courses but part of the programme's culture. By being clear to students about expectations regarding independent and active study behaviour and integrate this approach into all parts of the programme this will become the normal daily routine within the programme. To realize this, it's important that the concept is supported by all staff members.

Explaining the flipped classroom approach

At the start of the fourth period a short introduction was given to students about the flipped classroom concept. Evaluation results show that students are still insecure about what is expected from them in this new setting, causing some resistance to the new approach while separate components of this approach are appreciated. A better and more thorough

explanation about why the flipped classroom approach works and how it works can take away some if these insecurities (De Boer and Winnips, 2015).

Smaller groups

A lot of students, especially during their first year at the university, find it hard to interact in a large group. Students hesitate to ask a question or share their ideas in fear of looking 'dumb' in front of their peers. Interaction often is limited to students sitting on the first two rows. Having a question hour in smaller groups (e.g. 30 students) could lower the threshold to interact.

Spreading study load

In the survey and the panel discussion students reported that the weekly schedule for the math course was quite full and that the workload was not equally spread over the weeks, making it hard to finish all the preparation assignments, especially during the first weeks. Once fallen behind, it's hard to catch up and participation to lectures and diagnostic tests seems less useful when not all subjects have been studied yet. Relieving the workload a little could give students the possibility to catch up.

Development of instructional videos

Some students report to have a need for a (short) oral explanation of the theory before starting to work on the assignments. The videos found are not perceived as a satisfying substitute. Sometimes the quality of the video is insufficient. Also students like to see and hear someone from their own university, referring to specific pages in their math book, etc. What could meet their needs is to develop short instructional videos where the math lecturer provides students with an oral explanation on each topic.

Methods and tools supporting active preparation

Finally, several things could be done to encourage student preparation and participation in the existing set-up. Students could for example work in groups discussing a specific topic or assignment during the first part of the lecture. Then, during the second part of the lecture groups can be asked to give a short explanation to fellow students on 'their' topic or demonstrate the solution of a particular assignment on the chalkboard. Also online tools exist that support students in (collaboratively) preparing their classes or reading materials at home. The role of the lecturer as a stimulator of active learning and peer learning is essential here.

Flipped math 2.0

Based on these recommendations, several changes were made in the first year curriculum and the setup of the math course.

Exams and resits from other courses were moved to the math-free week in the middle and also towards the end of the module (after the math course) to reduce competition from other courses. Elements of the flipped classroom setup were introduced in math courses in the preceding quartiles. The effects and importance of active and self-responsible learning were explained and emphasized during the entire first year.

With regard to the math course itself, the group was split in two subgroups to lower the threshold for students to ask questions and stimulate interaction. The workload was spread more evenly over the weeks and the amount of self-study assignments was slightly reduced. Also, the diagnostic test was moved to Monday morning to give students more time to practice and process the weekly subject matter. During the question hour, active participation will be stimulated by placing students in small groups (3 to 4 participants) and presenting them with mathematical problems to solve together.

The course will run in the modified setup in the fourth quartile of this academic year (April - June 2016) en will be evaluated in the exact same way to allow for comparison of the results.

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