Improved Study Results with Advanced Teaching Environment

Dr. ing. A.H.W. (Piet) van der Zanden

University Corporate Office
Shared Service Centre – ICT, Educational Technology
Delft University of Technology (The Netherlands)
a.h.w.vanderzanden@tudelft.nl

1 Synopsis

Chalkboard pedagogy is still going strong within higher education. It makes students clear how reasoning takes place instead of just presenting facts. While thinking aloud the instructor simultaneously produce and write arguments in successive order on the board in order to visualise the reasoning. Students see the process and structure of the step-by-step arguments to recognise patterns and interconnections [1]. At the same time such talking-writing pedagogy loses connection with the contemporary but pressing movement of Open & Online education practices. The direct consequence of online practices is that materials, instructions, practices and assignments all are becoming digital. Successively, the chalkboard should follow this digitisation in order to fit with the upcoming blended classes.

Modern day mathematics teachers are avid users of ICT applications. An advanced teaching system was developed for their convenience at Delft University of Technology. In 2012 this system was introduced at the Faculty of Mechanical, Maritime and Materials Engineering for first year mathematical courses. Students have been very enthusiastic about this sophisticated way of math teaching. In a former study 'Advanced Teaching with Virtual Chalk and Four Parallel Video Signals' both instructors and students were approached how they have experienced this new system [2]. The outcome was absolutely positive, hence we wondered if the motivated statements would be reflected within their final study results.

This paper is a successive study concerning advanced teaching aiming at the results of students who participated the four-quadrant pedagogy. It aims at the courses Linear Algebra and Calculus of student cohorts from the academic years 2012-2013, 2013-2014 and 2014-2015 given by dr.ir. Johannes Maks. It also aims at study rate and failure rate. The results of this lecture setting are very satisfying and compete with active learning settings.

2 Linear Algebra and Calculus Courses taught with Advanced Teaching System

First year students at the Faculty of Mechanical, Maritime and Materials Engineering (3mE) of Delft University of Technology (TU Delft) follow two mathematical courses divided over four 10-week periods. The students were randomly assigned into cohorts of up to about 80 students. Each cohort was assigned a dedicated math instructor and timetabled in a certain lecture hall during the remainder of that first academic year.

The James Watt Hall, as one out of fourteen lecture halls of the faculty, was upgraded with an advanced teaching system in 2012 [2]. It makes use of virtual chalk through an interactive SMARTboard in combination with a quad videosignal presentation system. The four signals are formatted and presented as one four-quadrant projection; top left, top right, bottom left and bottom right. Mathematical instructor Johannes Maks uses the top left quadrant for a prepared PowerPoint to present main definitions, concepts and theorems of his courses. He uses the top right and bottom left quadrants as virtual chalkboards, and the bottom right quadrant for computer application Maple to demonstrate results that would be too complex to work out by hand. The bottom right quadrant is used also to show online materials or PDF subject matter. Figure 1 shows an impression of his mathematical practice.

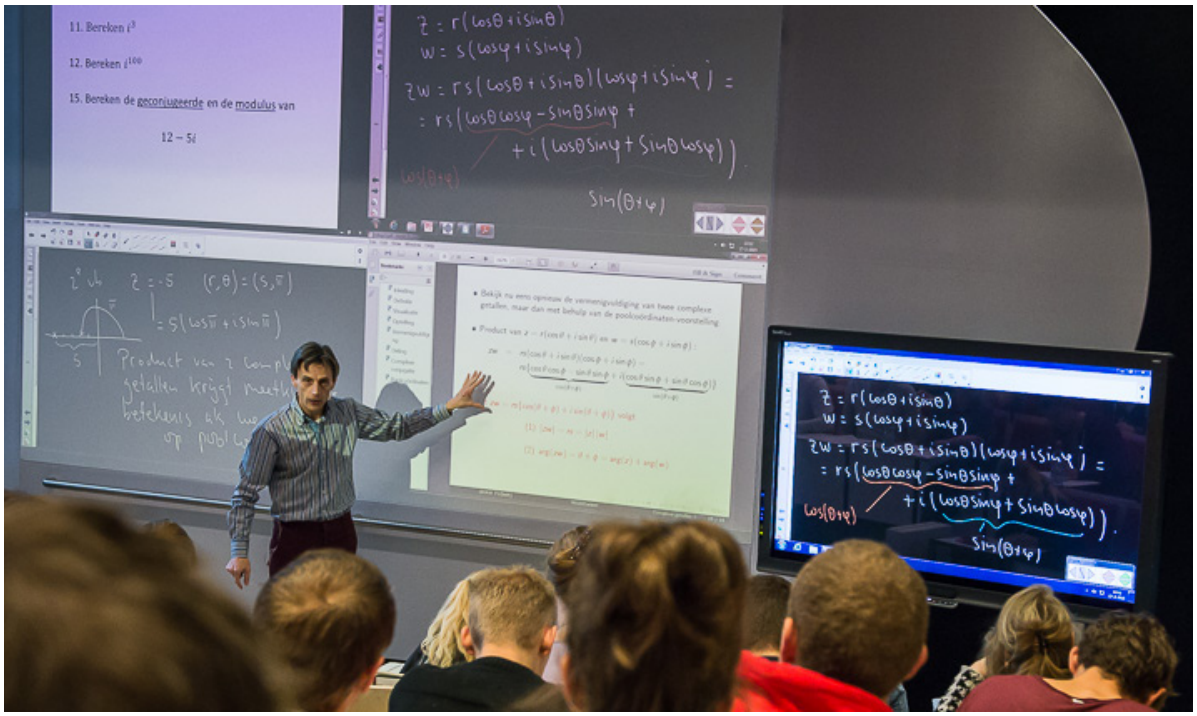

Figure 1: Math instructor Johannes Maks using four-quadrant pedagogy with interactive SMARTboard as input and control. Picture taken by Annemieke van der Kuil from PhotoA.nl.

Nine student cohorts, who have followed these particular mathematical classes, were approached to assess the advanced teaching. The results of 457 completed questionnaires and 238 students' comments delivered very positive results about the use of this advanced instruction set, taking the talking-writing pedagogy to a next level [3].

The education's quality, as a multifaceted and objective concept, was asked to grasp the students' opinion about the parallel presentation of video signals and SMARTboard. Striking was the absolute positive response of over 97 percent valuing the system with good to perfect. Also the collected quotes were great, such as "An outstanding way of teaching that more lecturers should practice, why do you think that the John Watts Hall is completely loaded", "It is because of this installation and lecturer Maks that I have been following all courses", "SMARTboard is brilliant, my compliments", "Fantastic that notes remain visible", "It operates perfectly, please install this system in all lecture halls", "A fine substitution for chalkboards", "Multiple windows have a huge advantage", "Installation is absolutely perfect, definitely an added value" and above all "Education is much clearer with this system".
Students were very positive about this advanced system, but do their motivated comments also lead to better study results?

3 Research Questions

The positive student attitudes have stimulated us to do a more profound study into their results. This study was not planned on beforehand, hence data had to be collected from several sources and synchroniced with studentnumber as key variable. We knew that all first year students were randomly assigned into cohorts at the start of term and had to reside therein for the rest of the academic year. At the same time we knew from student surveys and interviews that some of them swapped classes because they wanted to participate the four-quadrant pedagogy despite the assignment to other groups. Furthermore, we know that several instructors gave these first year math courses, therefore personal influences count their part. Still, we assume similarity between classes, which means that the findings of this study cannot be conclusive. Nevertheless, we found it interesting to gain a general feel: would the motivated students' attitudes about the new advanced teaching system be an indicator for better results. Driven by curiosity we have defined three research questions based on the discrimination of two student groups:

1. Participants of four-quadrants math pedagogy in John Watts Hall of 3mE
2. Students lectured with tradional math pedagogy in conventional lecture halls

3.1 Research question 1

In the initial academic year two mathematical courses, each consisting out of two parts, are compulsory for all the first year students of 3mE. An academic year is spread over four 10-week periods. In the first 10-week period the math course Calculus 1 is timetabled, in the second 10-week period the course Linear Algebra 1, in the third period Calculus 2, and in the final period Linear Algebra 2.

The first research question addresses the idea that students who appreciated the four-quadrant pedagogy should also score higher figures for their math courses. Hence the following alternative hypothesis was defined:

Four-quadrant pedagogy delivers higher scores for Calculus and Linear Algebra courses

3.2 Research question 2

Next to the scored math figures we would like to know what the average score of gained education credits is for the complete first year. During an academic year a maximum of 60 education credits (EC) may be achieved. We would like to compare the students who followed four-quadrant pedagogy math courses to the others taught with traditional lectures. We would like to define the gained

number of education credits within the academic year as Study Rate. The second hypothesis is defined as:

Four-quadrant participants have a higher study rate compared to traditionally taught students

3.3 Research question 3

Finally, we are interested in the Failure Rate of the first year students as opposite to Study Rate. Failure Rate is defined as the students who stopped their study or got a negative advice from the faculty. Students are expelled from college when they gained less than 45 ECs in their first academic year. The third hypothesis is defined as:

Four-quadrant participants have a lower drop-out compared to traditionally taught students

4 Method

In order to discover if the four-quadrant pedagogy has positive influence on study results we have distinguished two groups of students: 1) those who have participated the math classes in the John Watts Hall and 2) those who were taught in other lecture halls.

Staff from 3mE has ramdomly assigned students into several cohorts, hence we claim them as independent groups. An overview was created from several sources with anonymous studentnumber as primary key, the initiation year, and group assignment in relation to education period. In such way we could derive an overview with number of students per education period.

Four 10-week periods are present in the academic year with scheduled mathematical courses: Calculus 1 in the first 10-week period, Linear Algebra 1 in the second period, Calculus 2 in the third period, and Linear Algebra 2 in the fourth period. The assigned student groups could be traced back with the help of Ewoud van Luik of the Faculty's Education and Student Affairs department. Unfortunately, the assignments of the 2012 cohorts for the third and fourth period were not available anymore. Hence these groups were left out from the study.

Three academic years with scored figures for the math courses were collected thanks to Danielle Rietdijk from Faculty 3mE. The student groups are named Cohort2012 for students who have studied in the period from September 2012 to July 2013, Cohort2013 for those who have studied from September 2013 to July 2014, and Cohort2014 for those who have studied from September 2014 to July 2015.

Study results for all first year courses have been collected from Ron van Velzen of the University Corporate Office. Also the university's recommendations for students by the end of year to continue or stop their study were retrieved from Ron van Velzen.

Over the years the several math courses got different names while the content remained the same:

WI1030WBMT	Wiskunde 1 (with calculus 1 in period 1 and Linear Algebra 1 in period 2)
WI1031WBMT	Wiskunde 2 (with Calculus 2 in period 3 and Linear Algebra 2 in period 4)
WI1250WBMT-12	Calculus 1 in period 1
WI1251WBMT	Calculus 2 in period 3
WI1313WBMT	Linear Algebra 1 in period 2
WI1314WBMT	Linear Algebra 2 in period 4

The datasets were cleansed from entry test results (instaptoets) and midterm formative tests (formatieve tussentoets).

A complete curriculum rearrangement took place between academic years 2012-2013 and 2013-2014. Thus different course lists were composed to select the appropriate curricula for course codes and course names. Some courses hold more components with for instance a test or sub exam. Unfortunately not all data for the scored figures were available or retrievable, these courses are indicated with a Not Available (NA). Table 1 presents an overview of the courses with a grand total of 60 ECs for each academic year 2012, 2013 and 2014.

Table 1: Overview of Courses for 3mE First Year Curricula of 2012, 2013 and 2014 with Grand Total of 60 ECs

2012			2013			2014		
Course	EC		Course	EC		Course	EC	
WI1250WBMT-1	3	exam	WI1030WBMT	3	exam	WI1030WBMT	3	exam
WI1251WBMT	3	exam	WI1030WBMT	3	exam	WI1030WBMT	3	exam
WI1313WBMT	3	exam	WI1031WBMT	3	exam	WI1031WBMT	3	exam
WI1314WBMT	3	exam	WI1031WBMT	3	exam	WI1031WBMT	3	exam
WB1114-12	3	test	WB1130-T1	1	exam	WB1130-T1	1	exam
WB1114-12	3	exam	WB1130-T2	3	NA	WB1130-T2	3	NA
WB1115-12	4	exam	WB1130-T4	3	exam	WB1130-T4	3	exam
WB1116	4	exam	WB1530-T1	2	exam	WB1530-T1	2	NA
WB2104	3	exam	WB1530-T2	5	exam	WB1530-T2	5	exam
WB3101-11	3	exam	WB1630	6	NA	WB1630	6	NA
WB4100-12	3,5	exam	WB1631	0	test	WB1631	0	test
WB5104-12	3	exam	WB1631-T2	6	exam	WB1631-T2	6	exam
WB6101-12	3	test	WB1632-T1	1	test	WB1632-T1	1	NA
WB6101-12	3	exam	WB1632-T2	5	exam	WB1632-T2	5	exam
WBTP113-12	1,5	exam	WB1633-T1	4	NA	WB1633-T1	4	NA
WBTP113-12	2	exam	WB1633-T2	3	exam	WB1633-T2	3	NA
WBTP114-11	2	exam	WB1634-T1	4	exam	WB1634-T1	4	exam
WBTP115-12	1,5	NA	WB1634-T2	3	exam	WB1634-T2	3	exam
WBTP115-12	4	NA	WB1635-T1	4	NA	WB1635-T1	4	NA
WBTP115-12	4	NA	WB1635-T2	3	exam	WB1635-T2	3	exam
WBTP117-12	0,5	NA						
Total EC	**60**			**60**			**60**	

Two final datasets were composed. The first dataset holds the students' scores for all first year courses for the academic years of 2012, 2013 and 2014. It lists student number, cohort, coursename, exam date, figure, course credit, and group assigments in 27862 records. The second dataset contains student number, cohort, number of gained credits, study advice, and group assignments in 1159 records.

5 Study results for research question 1: Four-Quadrant pedagogy delivers higher scores for Calculus and Linear Algebra Courses

Table 2 presents the number of students who participated the four-quadrant pedagogy for the academic years 2012-2013, 2013-2014 and 2014-2015. It shows the number of participants for each of the four math courses at the left half. The right half of Table 2 shows the number of students who followed similar math courses but in traditional lecture halls. No data was available for the third and

fourth periods of cohort 2012, meaning that no data could be analysed for Calculus 2 and Linear Algebra 2 of the academic year 2012-2013.

Table 2: First Year 3mE Students following Math Courses with Four-Quadrant Pedagogy and Traditional Pedagogy

Cohort	4Q pedagogy				Tradional pedagogy			
	Calculus 1	Algebra 1	Calculus 2	Algebra 2	Calculus 1	Algebra 1	Calculus 2	Algebra 2
2012	54	48	NA	NA	293	299	NA	NA
2013	60	50	66	66	361	371	355	355
2014	61	56	50	44	313	313	253	274

The students following the four-quadrant pedagogy and traditional chalk pedagogy are considered independent groups because they were assigned randomly. We want to compare the means of scored figures for the four math courses. The SPSS independent samples T-test helps us to determine the differences of the average scores for Calculus and Linear Algebra. In table 3 the means of the two distinguished student groups are presented.

Table 3: Means of Scores for the Cohorts 2012, 2013 and 2014 distinguished by Pedagogy

Cohort	4Q pedagogy				Tradional pedagogy			
	Calculus 1	Algebra 1	Calculus 2	Algebra 2	Calculus 1	Algebra 1	Calculus 2	Algebra 2
2012	6.163	**6.615**	-	-	6.202	**6.129**	-	-
2013	5.725	5.568	5.712	5.712	5.593	5.618	5.593	5.593
2014	6.344	**6.571**	6.170	**7.114**	6.121	**6.177**	6.077	**6.555**

Table 3 shows us that many scores are compatable with each other. Only courses Linear Algebra 1 for cohorts 2012 and 2014 and Linear Algebra 2 for cohort 2014 show significant results. The values are indicated in bold with a coloured background.

Linear Algebra 1 for cohort 2012 shows a significant difference in means of nearly 0.49 study points with a confidence interval of 95 %. The variances of the two groups are not assumed equal according to the Levene's test, which is standard procedure for testing independent groups. The significance test delivers a value of 0.037, which means that we can safely conclude that the 0.49 higher scored figures are not due to chance only.

Evenso, Linear Algebra 1 for cohort 2014 shows a significant difference in means of nearly 0.4 study points for a confidence interval of 95 %. The variances of the two groups are assumed equal according to Levene's test. The significance test delivers a value of 0.031 meaning that the four-quadrant participants scored 0.4 points higher than students who participated the traditional pedagogy.

Linear Algebra 2 for cohort 2014 shows a significant difference in means also. It is an interesting 0.56 study points higher with a 95 % confidence interval and equal variances. The significance test delivers a value of 0.017 meaning that four-quadrant pedagogy participants certainly scored higher figures compared to traditional pedagogy.

6 Study results for research question 2: Four-Quadrant participants have a higher study rate compared to tradionally taught students

When students pass a course, they gain education credits (EC). Such credits are proportional with the study load of a course. A nominal study year is build around a number of courses with a grand total of 60 ECs. Study rate is defined as the total of gained ECs during an academic year.

Instructors from 3mE who have been lecturing construction courses in the John Watts Hall have mostly made use of a mobile but conventional chalkboard in stead of the advanced teaching possibilities. Some of them do have used the SMARTboard as digital chalk medium, but not the possibility to use multiple videosignals simultaneously. Unfortunately, we could not recover which lecturer have used some parts of the advanced system and which lecturer did not.

We have compared the student groups that were timetabled in the John Watts Hall with the students scheduled in the other traditional lecture halls. Table 4 shows an overview of the 3mE courses for the several academic years. We kept the Dutch course names to prevent confusion due to translation. Not all 2014 data were available, these are indicated with NA.

Table 4: Overview of Course Codes for 3mE First Year Curricula

		2012 Means				2013 Means		2014 Means	
Course	CourseName	John Watts	Other halls	Course	CourseName	John Watts	Other halls	John Watts	Other halls
WB1114-12	Statica	6.398	6.038	WB1130-T1	Matlab	7.036	7.071	6.264	5.995
WB1114-12	Statica	6.174	6.000	WB1130-T4	OWS, Materiaalkunde	5.885	5.572	5.645	5.589
WB1115-12	Sterkteleer	6.113	5.797	WB1530-T1	Warmteoverdracht	5.463	5.929	NA	NA
WB1116	Dynamica A	5.825	5.459	WB1530-T2	Thermodynamica en St	5.132	5.317	4.500	4.712
WB2104	Regeltechniek	7.063	6.839	WB1631	SterkteleerForma	3.577	3.500	4.178	4.269
WB3101-11	OWS 1 Eindtoets	6.298	6.074	WB1631-T2	SterkteleerTentam	4.397	4.599	5.339	5.182
WB4100-12	Thermodynamica 1	5.992	5.694	WB1632-T1	DynamicaTentamen	5.471	5.523	NA	NA
WB5104-12	Vervaardigingskunde	**7.440**	**6.515**	WB1632-T2	DynamicaTentamen	4.876	4.860	5.883	5.919
WB6101-12	Materiaalkunde 1	6.146	6.191	WB1633-T2	OWS, Materiaalkunde	5.202	5.090	NA	NA
WB6101-12	Materiaalkunde 1	6.797	6.720	WB1634-T1	Groepswerk & Prof.	7.233	6.900	7.514	7.453
WBTP113-12	Project 1 Matlab	5.733	5.602	WB1634-T2	OWS, Materiaalkunde	4.838	5.098	**7.142**	**6.589**
WBTP113-12	Project 1	6.576	6.583	WB1635-T2	OWS, Vervaardigen	5.426	5.515	5.962	5.859
WBTP114-11	Project 2	8.143	7.986						
Total EC		**6.515**	**6.269**			**5.378**	**5.415**	**5.825**	**5.730**

If we study the figures from Table 4 then we only notice two significant higher means for students who have visited the John Watts Hall, namely course WB5104-12 for the 2012 cohort and course WB1634-T2 for cohort 2014. Comparing the total means indicate minor differences, cohort 2013 residing in the John Watts Hall even scores lower than students from other halls. As a consequence we can only conclude that no obvious difference in scores is present between students visiting the John Watts Hall and students visiting other lecture halls for courses that are part of the 3mE curriculum.

Course credits are gained when students pass their exams with scores higher than the pass mark of 60 percent. How would the study rate be for the two different student groups despite the non-

distinguisable scores from Table 4. In order to answer this question we focus again on the math courses for they made use of the four-quadrant pedagogy. Table 5 presents the means of the gained ECs of first year students who paticipated the new pedagogy compared to traditional pedagogy for the academic years 2012-2013, 2013-2014 and 2014-2015. The table shows the number of participants and their means of collected credits.

Table 5: First Year 3mE Students with Average of Collected Education Credits for Academic Years 2012, 2013 and 2014

Cohort	4Q Pedagogy	Means (EC)	Traditional Pedagogy	Mean (EC)
2012	101	**47,2**	246	**42,8**
2013	148	**42,8**	267	**38,4**
2014	46	**46,5**	351	**38,9**
Totals	295	45,5	863	40,1

All cohorts following four-quadrant pedagogy collected a significantly higher amount of credits when compared to traditional pedagogy. The variances are not assumed equal for non of the cohorts. Cohort 2012 collected a difference in means of 4.4 education credits with a significance test value of 0.007 and confidence interval of 95 %. Cohort 2013 collected a 4.4 higher credit means also but with a significance of 0.01. Finally, cohort 2014 collected an impressive 7.6 extra credit points with a significance of 0.0035.

When we express the differences into a ratio parameter then cohort 2012 scored a (47.2 – 42.8) / 42.8 * 100 % = 10.3 percent better result with the four-quadrant pedagogy, cohort 2013 scored (42.8 – 38.4) / 38.4 * 100 % = 11.5 percent better, and cohort 2014 even scored (46.5 – 38.9) / 38.9 * 100 % = 19.5 percent better.

7 Results for research question 3: Four-Quadrant participants have a lower dropout rate compared to traditionally taught students

First year students have a target to make. A maximum of 60 ECs may be scored within an academic year, but when a student scores lower than 45 ECs one is expelled from college. Only a sound reason can counteract such radical decision. Our university uses four different marks to value the effort of a student.

- A = Aangehouden, it means on hold. It stands for the situation that a student did not score the threshold of 45 ECs, but had a good reason for it. That reason was declared legal, hence the student is allowed to continue with his or her study.
- N = Negatief, it means negative. The student is not allowed to further his study for this educational track and expelled from college.
- P = Positief, it means passed to the next academic year. The student has at least scored 45 ECs up to the maximum of 60 ECs in his or hers first academic year.
- S = Staker, it means dropout. The student has taken himself or herself the decision to stop with the study.

Failure Rate is defined as the sum of negative advice and dropout divided by the total number of participants for that particular academic year. Table 6 shows the presented marks for the cohorts

participating the four-quadrant pedagogy. Table 7 shows the presented marks for the cohorts that followed traditional pedagogy.

Table 6: Failure Rate for Students Following Four-Quadrant Pedagogy

Advice	A	N	P	S	Totals	Failure Rate
2012	4	15	77	5	101	**19.8**
2013	6	38	93	11	148	**33.1**
2014	2	5	36	3	46	**17.4**
Totals	12	58	206	19	295	

Table 7: Failure Rate for Students Following Traditional Pedagogy

Advice	A	N	P	S	Totals	Failure Rate
2012	8	37	171	30	246	**27.2**
2013	12	59	151	45	267	**39.0**
2014	11	92	198	50	351	**40.5**
Totals	31	188	520	124	864	

The calculated Failure Rate differs quite substantially between the students who followed four-quadrant pedagogy and those who did traditional pedagogy. When we express the differences into a ratio parameter then cohort 2012 scored a (27.2 – 19.8) / 27.2 * 100 % = 27.2 percent lower result with four-quadrant pedagogy, cohort 2013 scored (39.0 – 33.1) / 39.0 * 100 % = 15.1 percent lower, and cohort 2014 scored a stunning (40.5 – 17.4) / 40.5 * 100 % = 57 percent lower.

8 Conclusion

Since 2012 an advanced teaching environment was installed at the John Watts Hall of the Faculty of Mechanical, Maritime and Materials Engineering of TU Delft. Students and math instructors were extremely positive about the four-quadrant pedagogy that became possible with this system, but would the motivated students also score better results. Especially mathematical instructor Johannes Maks from Applied Mathematics of the Faculty of Electrical Engineering, Computer Science and Mathematics was and is an avid user. He and his students were followed for evaluation reasons. A more profound study was conducted into the effects of four-quadrant pedagogy over three full academic years, thus we traced back relevant sources. Not all data could be retrieved, and a direct cause-effect relation is not allowed to be made because of too many variables. Still we were able to obtain an impressive effect due to the new pedagogy.

We have focussed on the four math courses Calculus 1, Linear Algebra 1, Calculus 2, Linear Algebra 2 for the cohorts 2012, 2013 and 2014 and treated all participating first year students as two independent student groups. The study reveals significant mean differences for three mathematical courses: Linear Algebra 1 for cohort 2012 scored 0.49 higher figures when four-quadrant pedagogy was conducted. Linear Algebra 1 for cohort 2014 scored 0.4 higher and Linear Algebra 2 for cohort 2014 even scored 0.56 points higher.

When we focus on the gained education credits, our study reveals a significant difference in means for all cohorts. The study rate for the 2012 cohort improved with 10.3 %, cohort 2013 with 11.5 % and cohort 2014 with a stunning 19.5 %.

If we finally focus on the failure rate for cohort 2012, it is 27.2 % lower for the participants of four-quadrant pedagogy, for cohort 2013 that is 15.1 % lower and for 2014 it even is 57 %, which are pretty impressive results.

A clear difference is demonstrated between 4Q pedagogy and traditional pedagogy although data was a bit incomplete. Now that the pilot study is coming to its end and state-of-the-art four-quadrant teaching environments are implemented over our campus, we are confident that Science, Technology, Engineering and Mathematics (STEM) education may profit from this new four-quadrant pedagogy. Moreover, with a good alternative for physical chalk and incorporation into a pedagogy it can build bridges between campus classes, blended settings and online practices.

9 Discussion

The largest and most comprehensive meta-analysis to date of undergraduate STEM education questions the traditional lecturing practice and advises active learning as the preferred teaching practice in regular classrooms [4]. The study of Freeman cs revealed that student scores were improved by 6 % in active learning settings versus lecture settings. Additionally, they claim that students in traditional classes are 1.5 times more likely to fail. The greatest effects were found for small classes ($n < 50$).

If we compare our findings with Freeman's study and convert the student scores for Linear Algebra 1 of cohort 2012 into percentages, then these scores show an improvement of (0.49 / 6.129) * 100 % = 8 %, the scores for Linear Algebra of cohort 2014 were improved by (0.4 / 6.177) * 100 % = 6.5 %, and Linear Algebra 2 for cohort 2014 even with (0.56 / 6.555) * 100 % = 8.5 %.

Furthermore, if we compare our findings concerning failure rates with the phrase '1.5 times more likely to fail' [4] than we should consider the number of the university's advice N (Negatief) and S (Staker) for both pedagogies divided by their totals for all three academic years. This makes (188 + 124) / 864 = 0.361 for traditional pedagogy classes versus (58 +19) / 295 = 0.261, resulting in 1.4 times more likely to fail.

Four-quadrant pedagogy is new, but it still belongs to what is named lecture setting. We think that our results counter the advice of Freeman cs for leaving lectures as pedagogy. Quite the contrary, if we take both studies in account, how interesting would it be when four-quadrant pedagogy is added with active elements, such as responsive clicker tools and periodical pauses in which students clarify their taken notes to a companion in two-minute breaks.

References

[1] Greiffenhagen, C. (2014). "The Materiality of Mathematics: Presenting Mathematics at the Blackboard." British Journal of Sociology: 27.

[2] Zanden, A. H. W. v. d. (2013). Advanced Teaching with Four Parallel Video Signals. 7th International Technology, Education and Development Conference, Valencia, Spain, IATED.

[3] Zanden, A. H. W. v. d. (2014). Advanced Teaching with Virtual Chalkboard and Four Parallel Video Signals, Delft University of Technology (Revised and Expanded): 14.

[4] Freeman, S., et al. (2014). "Active Learning increases student performance in science, engineering, and mathematics." PNAS 111(23): 6.

Acknowledgement

The author would like to express his gratitude first of all to the motivated instructor and of course the colleagues who delivered resources in order to complete the datasets for analysis of this study:

- Dr. ir. J.G. (Johannes) Maks, mathematics instructor from Delft Institute of Applied Mathematics of the Faculty of Electrical Engineering, Computer Science and Mathematics
- Drs. D. (Danielle) Rietdijk from the local Education and Student Affairs department of the Faculty 3mE for delivery of initial lists with student results.
- E.P. (Ewoud) van Luik from the local Education and Student Affairs department of the Faculty 3mE for the group assignments lists.
- R.W.J. (Ron) van Velzen, Head of Information Management from the central Education and Student Affairs department of the University Corporate Office for all anonymous student results.