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EQUITY AND EXAMINATION TIME PRESSURE IN FIRST YEAR MATHEMATICS FOR ENGINEERS

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ABSTRACT

The ‘gender mathematics gap’ which persists in many countries means that women students may, on average, have less high school preparation in mathematics than men students entering engineering education. This in turn could impact their performance in first-year exams and thus reduce women’s participation in engineering programs. One factor that has been a focus of some interest in addressing equity issues in education is time-limited exams, which have been found to give rise to unfairness with respect to underrepresented students in a number of

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domains. In mathematics, time pressure has been found to be linked to increased student stress and to the use of less effective problem-solving strategies in assessment conditions. We sought to explore, therefore, the impact of reducing time pressure in a first-year engineering Linear Algebra course. We had 275 participants, of which 192 (69.8%) were men and 83 (30.2%) were women. Using a pseudo-experimental design in real-word conditions which controlled for teacher effects and assessment effects, we found that, when there was reduced time pressure, students with less prior mathematics performed better than when in a more time-pressured exam. Our results show that these students can learn the required Linear Algebra and can demonstrate their learning under appropriate conditions. This leads us to conclude that reducing time pressure in first year mathematics exams may contribute to improving the retention of women students in engineering education, particularly in cultural contexts in which a gender mathematics gap is prevalent.

1 INTRODUCTION

1.1 Exam length and equity in engineering education

Equity remains a persistent issue to be addressed in engineering education. Lichtenstein et al. note that in the US, for example, while the proportion of women enrolled in higher education has grown substantially since the 1980s, ‘‘minimal progress has been made in recruiting and retaining …women and minorities, into engineering programs’’ (Lichtenstein et al. 2014, 314). Similar patterns are evident in European engineering education (Barnard et al. 2012; Powell et al. 2012).

One factor which plays a role in this is the place of mathematics in the initial education of engineers. Lower prior performance in math has been found to be a factor in non-retention of students in engineering education (Takahira et al. 1998; Falkner et al. 2010; Falkner et al. 2014). This in turn is linked to gender since, despite a narrowing of the gap, boys continue to have, on average, higher mathematics achievement at upper secondary school level in many countries (OECD 2019). Indeed, the comparatively better performance of boys in mathematical attainment is actually higher than the OECD average in many European countries including Switzerland, Luxembourg, Austria, Germany, France, Italy, Portugal, Belgium, Ireland, Spain and the United Kingdom. This ‘gender mathematics gap’ is not something that should be taken for granted or accepted, however: girls actually outperform boys in mathematics in other nearby European countries including Sweden, Norway and Iceland (OECD 2019, 25-26). Rather than linked essentially to sex, gendered differences in attainment are linked to persistent cultural beliefs about gender and mathematics, as well as to educational practices (OECD 2023). The issue is, therefore, not a biological one, but one linked to culture and social and educational structures.

If there are differences in average high school performance in mathematics, this in turn impacts on those same students when they enter university. Differences in prior knowledge like this can be understood in two different ways: either as a ‘deficit’ in some students that needs to be addressed through the students changing what they learn before coming to university, or as a ‘difference’ between students that needs to be taken into account in pedagogical choices of institutions. There is evidence that framing equity issues as one of ‘difference’ is productive insofar as changing the way we teach and assess in university can have an impact on equity in student success without simply transferring the burden for change onto the student themselves. For example, specific pedagogical choices such as the use of flipped classes (Hardebolle et al. 2022) or interactive teaching (Theobald et al. 2020) have been identified as having an impact on reducing attainment gaps for women and other underrepresented students in undergraduate science, technology and mathematics courses. It makes sense, therefore, to look at other aspects of teaching and assessment that may be contributing to attainment gaps for women and other under-represented groups.

One such factor that is worthy of consideration is examination time pressure. Although time-limitations in assessment are widely accepted as a normal practice, there is evidence that time-limited tests discriminate unfairly against students who are learning in a second language (e.g. immigrant students), those who are older than average, and those from other underrepresented backgrounds (see Gernsbacher et al. [2020] for a review of evidence). Caviola et al. (2019) found that there is a substantial body of literature that suggests that the imposition of time limits can increase stress associated with challenging tasks. Specifically looking at mathematics problem solving, there is also evidence that, as is expected from stress reactions, shorter time limits can lead to a shift to using suboptimal (heuristic rather than analytical) solution strategies (Gillard 2009). Since there is a known association between mathematics anxiety and gender (e.g. Hart and Ganley, 2019; Vos et al. 2023) this suggests that examination time pressure may well play a role in contributing to gender differences in performance.

In light of such findings, it is surprising to see that there are few studies which have explored the impact of time pressure on equity in mathematics learning. Caviola et al.'s review, for example, found only a handful of studies looking at university students, most of which were relatively small, and which typically did not use the kinds of mathematical problems being solved by engineering students in first year courses. Furthermore, while experimental studies have the benefit of being designed for internal validity, their findings often do not transfer into real world settings. Kim (2019) for example, found that in one review of trials aimed at transferring a previously validated educational intervention into real-life settings, only 11 of 90 trials yielded positive results. This suggests a need to test such ideas beyond experimental settings, under real-world conditions.

This, then, gives rise to our research question: does reducing time pressure in first year university mathematics exams have an impact in reducing the gender gap in attainment for engineering students?

1.2 Context of this study

As noted above, gendered patterns of mathematical performance differ depending on the education system and culture of the wider society. This study took place in Switzerland, where almost all students come from France and Switzerland, two countries in which the 'gender-mathematics gap' (i.e. boys having higher mathematics scores than girls on average) in high school is a little bigger than the average for the OECD as a whole (OECD 2019, 25-26).

In the technical university in question, women make up circa 29% of the first-year intake. While the students coming from France all had a scientific baccalaureate (French BAC) (and therefore substantial prior studies in mathematics), not all Swiss students have substantial mathematics in their high school. Of the students entering this university who had a Swiss high school diploma, over the years 2014-20, 56% of the men had taken the physics and mathematics option in high school (Swiss PAM), as compared to 33% of the women. In the same time period, counting all students (i.e. including both Swiss and others) 70% of first year men passed exams to allow them to enter second year, as compared to 65% of women.

2 METHODOLOGY

The purpose of this study was to explore if reducing time pressure in first year university mathematics exams would have an impact in reducing the gender gap in attainment for engineering students. This was done through a pseudo-experimental study. In the academic year 2019-20, the number of questions in the Linear Algebra exam for first year students was reduced, without reducing the time allocated to the exam, the difficulty of the questions or the amount of material covered in the course. This, therefore reduced the time pressure on students in the exam, while retaining other factors as constant. Students who took the exam in 2018-19 were identified as a control group (normal time pressure condition), while those who took the exam in 2019-20 were identified as the experimental group (reduced time pressure condition).

2.1 Participants

Table 1. Student participants, the examination condition and their high school diploma type

	French BAC	Swiss PAM	Swiss Other	Total
2018-19 (Control condition)				
Men	34	17	11	62
Women	19	7	9	35
2019-20 (Reduced time pressure condition)				
Men	57	45	28	130
Women	25	8	15	48
Total	135	77	63	275

As the university was interested in researching aspects of mathematics pedagogy at that time, students were invited to volunteer to be part of a study on pedagogical innovations. A total of 660 students volunteered to participate in the years 2018-19 and 2019-20. In the university at that time, the Linear Algebra course in the first semester of first year was taught by nine different teachers. Since one of the classes had a different pedagogical condition than others (a flipped class) it was excluded from this study. This study is then based on data from classes with eight different teachers (effectively ensuring that any findings are not simply the result of a factor related to a single instructor). We therefore retained for this study (a) students who were not involved in the flipped class condition, (b) students who had not previously taken first year (i.e. repeating students were excluded) and (c) students whose high school experience we could meaningfully categorise (i.e. those who studied for a high school diploma in France or Switzerland). This gave us 275 students, of which 192 were registered as men and 83 were registered as women (the university registration system did not allow students at that time to identify with a gender other than these two). The breakdown of students in terms of their registered gender and high school diploma type (i.e. French scientific BAC, Swiss PAM, Swiss Other) is in table 1.

2.2 Measures

The Linear Algebra exam was 80% multiple choice questions (common to all teachers) and 20% developed response questions (different across different teachers). The multiple choice questions were set by the teachers collectively and validated to ensure that the difficulty level was the same from year to year (this effectively controlled for assessment-related factors). Students who did not achieve a grade of 3.5 out of 6 on their mathematics and physics subjects in the first semester are not permitted to proceed to semester two and are instead redirected into a ‘foundations reboot program’ which must be passed before they can be readmitted to first year (it should be noted 3.5 is not a ‘passing’ grade – students need 4 out of 6 on average over two semesters to pass first year). Since our focus was on retention of students in the first year we focused on two measures. The first is grade, scored on a scale of 1 to 6, with 6 being the highest. The second is achieving a grade of 3.5 or higher (since lower grades mean not being allowed continue in the first year unless the ‘foundations reboot’ is passed).

In the control condition there were 24 multiple choice questions. In the reduced time pressure condition there were 22 multiple choice questions. The exam time in both cases was 3 hours and the 20% of developed response questions did not change.

2.3 Ethics

Students had all volunteered to take part in research on pedagogical innovation in mathematics education and had given their informed consent for their data to be used in research. The decision to reduce the time pressure in the exam was taken by the teachers and was done for all students to ensure fairness and equity of treatment for all. Thus, while the mathematics test condition was the same for all students (those who volunteered to participate in the research on pedagogical innovation and those who did not), only data from students who volunteered to have their data used in research was included in this study.

3 RESULTS

Table 2 presents the overall average grades for students on the Linear Algebra exam including both the 80% common part and the 20% questions individual to each teacher. As table 2 shows, the average grade went being below the level which barred students from entering the second semester (3.5) to a grade above that level in the reduced time pressure condition. This difference is statistically significant ($t = -2.11$, $df = 193.98$, $p = .03$).

Interestingly, the additional time made effectively no difference to the performance of those who had substantial mathematics in their high school experience (French BAC and Swiss PAM diplomas), for whom the final grade in the control condition was very similar to under the control condition (see the dashed grey line in Figure 1, below). There is however a clear difference in those who had a non-mathematical Swiss high school diploma, who had a higher grade average in the reduced time pressure condition (t = -3.18 df = 41.16, p <.01). In the control condition only 4 out of 20 participants with a non-mathematical Swiss high school diploma scored 3.5 out of 6 and were thus allowed proceed to the second semester (20%); in the reduced time pressure condition this rose to 22 out of 43 (51%).

Table 2. Grades of participating students in control and reduced time pressure conditions

	N	Mean Grade	Median Grade	Grade St. Dev.
Control (2018-19)	97	3.38	3.5	1.25
Reduced Time Pressure (2019-20)	178	3.71	3.75	1.22

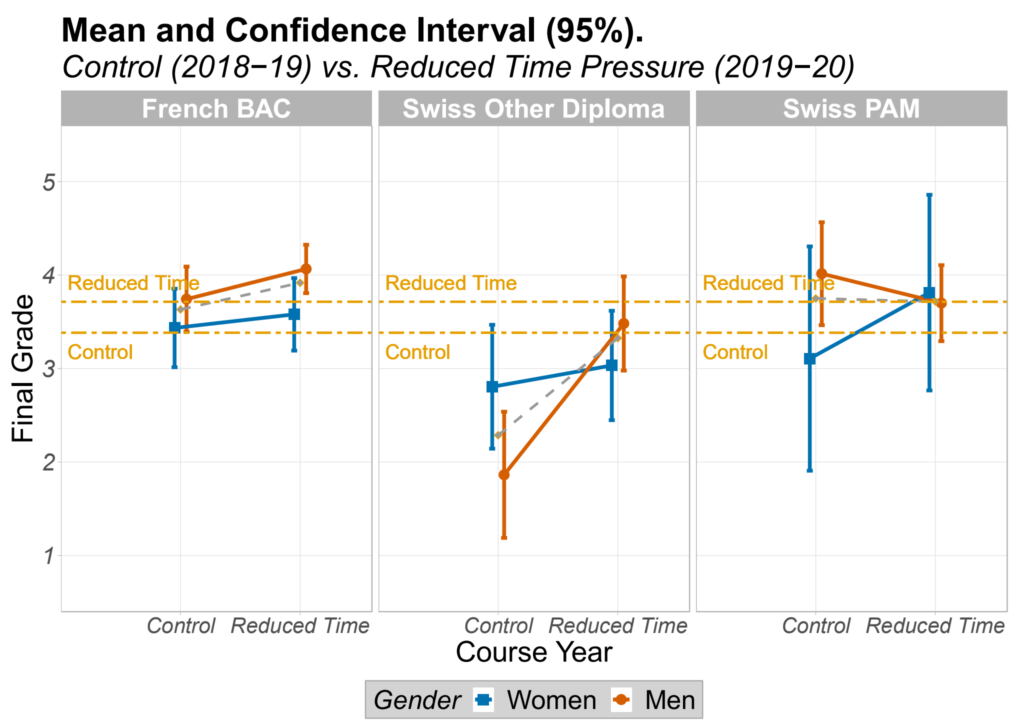

Fig. 1. Grades by gender, condition and high school diploma (including 95% confidence interval). The mean grade across groups is represented by dash-dotted horizontal lines. Dashed grey lines represented the weighted means for each condition and group.

Figure 1 (above) shows how the interaction between gender and prior mathematical experience in high school impacts upon this change. The improved performance of those who do not have substantial mathematics in their high school diploma (Swiss Other) is experienced by both men and women. This is reflected in the overall performance of women on the exam: their mean average grade rose from 3.21 (st. dev. = 1.11) in the control condition to 3.45 (st. dev. = 1.15) in the reduced time pressure condition (t = -0.96, df = 74.76, p = .34). This is reflected in an increase in the rate of women having a grade (3.5) that would allow them to enter the second semester: the rate in the time pressured condition was 15 out of 35 (42.9%). In the reduced time pressure condition this rose to 26 out of 48 (54.2%). Although Figure 1 shows a slight decline in grade for men with Swiss PAM backgrounds in the reduced time condition, and shows different levels of increased attainment between conditions for men and women with Swiss Other backgrounds, these differences are small enough that they are neither notable nor statistically significant.

4 ANALYSIS

The data shows that the difference in time pressure in the exam does appear to make some difference in student success in the exam. As Figure 1 shows, however, this improvement is not evenly distributed across all groups: the benefit is felt most acutely by those who have less mathematics in their high school diploma (Swiss Other Diplomas), a group in which women are over-represented. Unlike those who had more prior mathematics in high school, the grades obtained by this group are significantly higher in the reduced time pressure condition ($t = -3.18$, $df = 41.15$, $p < .01$). The specific psychological processes that explain this was not the subject of this study. It may be that students who have less prior mathematical practice have less fluency and therefore need more time to demonstrate their mathematical skills and knowledge. It may be (as studies cited by Caviola et al. [2019] found) that the time pressure increases stress and therefore leads to the use of less efficient solution methods for those students.

Whatever the actual psychological processes involved, the findings do seem to show that students with less prior mathematics (such as those with a Swiss Other diploma) can learn the required linear algebra knowledge and skills and can demonstrate that learning under the right conditions (such as a reduced time pressure exam). This in turn can be seen in a notable increase in grade by women students in our study, and an increase in women having the grades required to progress to the second semester. Unfortunately, the average grade for women in the reduced time pressure condition is still only 3.45, below the passing grade (4) and below the grade at which students are allowed to progress to the second semester (3.5). So a change in exam time, on its own, will not constitute a magic bullet to solve the 'gender mathematics gap'. However, it seems likely that there is no magic bullet to address this and rather there are only a range of strategies which each have an incremental effect and which together can have a meaningful impact. This data does suggest that time pressured exams may be one factor leading to the exclusion of both women and men students who did not have a strong background upon entry to university, and addressing this may be part of the solution.

This has clear implications for equity issues and the retention of women students in engineering education. As noted above, in the context of our study, the wider culture and the structure of high school education means that women, on average, come to engineering education with less prior mathematical experience than men. Creating assessments that allow those with less mathematical prior knowledge to show the mathematical knowledge and skills they have learned during the course is, therefore, one potentially important factor in improving equity. Reducing time pressure may well be one way of doing this.

As with any study, ours has some limitations. Our study is a real-world pseudo-experiment, which means we do not randomly assign students to control and reduced time pressure conditions. While the study effectively controls for multiple factors (teacher effects, assessment effects, prior mathematical background and gender), we cannot rule out some other factor impacting on the data. We would note however, that while this is a limitation, it is also a strength: the findings of the majority experimental studies do not survive transfer to real-world conditions (Kim, 2019) and what we have found is an impact in real-world conditions. A second limitation is that the number of women present in our study is relatively small, which means that we do not have enough power to find statistically significant differences. This is a function of the lower enrolment rates of women in our programmes: in fact we began with 660 participating students but once we controlled for prior study, gender, pedagogical differences and having repeated first year we were left with 24 women with a non-mathematical high school diploma. This highlights, once again, the challenges of doing real-world studies on gender and attainment in engineering education. Our study focused on the experience of women students. We are unable to say if this experience is shared by other under-represented groups, and thus this should be a focus of further research. A third limitation to be aware of is that gender differences in mathematics performance are not uniform across education systems and cultures, and so the findings from one place should not simply be applied in a different cultural context. A fourth limitation is that only one method of reducing time pressure in assessment (having fewer questions in the same time period) was studied here. There are other strategies for reducing time pressure, such as having more time and the same number of questions. These other strategies may also merit consideration.

5 CONCLUSION

Equity remains a persistent issue to be addressed in engineering education, including the retention of women students. Since, in many cultures and contexts, women come to engineering education with, on average, lower prior levels of mathematics education than men, one dimension of how we retain more women in engineering education is by ensuring that the impact of prior knowledge on their attainment in first year examinations in mathematics is minimised. In this study we sought to explore how we could adapt assessment to ensure more equitable outcomes for our diverse student intake.

Although time-limited assessments are a widely unquestioned part of the ritual of university mathematics, there is some evidence that these kinds of assessments can be unfair (Gernsbacher et al. 2020). There are also specific reasons for thinking that they might contribute to gender inequities in mathematical attainment (Caviola et al., 2019). Using a real-world pseudo-experiment, we explored the impact of time pressure on students' attainment in a first year Linear Algebra exam. We found that in a less time pressured condition, students with less prior mathematics can demonstrate the required linear algebra knowledge and skills while similar students in a more time pressured situation did not demonstrate the same learning. Students with a strong mathematical background do not benefit nor suffer from such a measure.

Creating assessments that allow those who had less mathematical experience in high school to show the mathematical knowledge and skills they have learned in university is, therefore, a potentially important contribution to improving women's retention in engineering education.

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