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Gender, Mathematics and AMSI's ChooseMaths Program: Analysis of Students' Attitudes to Mathematics

AMSI AUSTRALIAN MATHEMATICAL SCIENCES INSTITUTE

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Executive Summary

The underrepresentation of women in mathematics throughout the educational pipeline and in the mathematics-based workforce motivated the ChooseMaths program, a partnership between the Australian Mathematical Sciences Institute (AMSI) and the BHP Foundation which aimed to build mathematical capacity and increase participation of girls and young women in Science, Technology, Engineering and Mathematics (STEM).

Gender differences in mathematics performance exist from about Year 3 with a widening gap across the school years, and the differences in performance and achievements of girls and boys are easy to measure and are well documented in the literature. In contrast, girls' and boys' attitudes to mathematics are more difficult to quantify and assess objectively. However, the latter are related to or may, in fact, be the main underlying cause of observed difference in performance between the genders.

This report examines whether gender differences exist in students' attitudes to mathematics and how their attitudes change following growth mindset ideas and specially designed mathematical activities. Changes in attitude, and in particular, positive changes in students' self-perceived ability to learn mathematics impact on their engagement and performance.

As part of the ChooseMaths program, data from more than 8000 students in 120 schools around Australia were collected from 2015-2019. This report provides a comprehensive analysis of the student data and focuses on attitudes of students towards mathematics. The attitudes of interest include students' confidence, enthusiasm for mathematics and their mindset towards learning new mathematics.

The analyses include summary statistics stratified by gender and school year and allowing comparisons of attitudes before and after *treatment*. The results show that girls start with lower confidence and enthusiasm but their gains are larger than those seen in boys. Further, the differences in attitude changes between boys and girls and between cohorts of students are much larger than the difference in attitudes between the genders. The summary statistics are enhanced by deeper statistical analyses which lead to a characterisation of distinct student cohorts and highlight the factors that contribute most to the change in attitude following suitable intervention or treatment.

The findings obtained from these analyses are encouraging: they show that attitudes to mathematics improve and confidence in one's mathematical ability increases with appropriate treatment. In addition, more positive attitudes to mathematics, especially of girls and young women, may aid in addressing the underrepresentation of women in mathematics throughout the educational pipeline and in the mathematics-based workforce.

Contents

Recommendations

- Integration of mathematical activities into the mathematics teaching, including new textbooks, and constructive evaluation of the effects on students' attitudes.

  Rationale
  Students, and especially female students, can be motivated by and are known to respond positively to mathematical activities and growth mindset ideas designed to increase their enthusiasm for and confidence in their mathematical ability. As a consequence of increased enthusiasm and confidence, students attempt more challenging mathematics task and experience success with these. In turn this increases their confidence for the mathematical tasks.

- Investigation of student cohorts that are 'left behind' and development and implementation of strategies, activities and opportunities to re-engage these student cohorts with mathematics.

  Rationale
  Small proportions of students at all year levels experienced only a very marginal increase in enthusiasm and confidence through growth mindset and other mathematical activities, including a reasonably confident cohort of students. The latter consists of more boys than girls who somehow lost interest.

- Provision of programs or modules for primary and secondary teachers to interact and decrease the differences in teaching modes.

  Rationale
  Of concern is the decrease in attitudes of students when they enter secondary school and during the first years at secondary school. Different teaching modes in primary and secondary school, and potentially also the teaching by out-of-field teachers in the early years of high school are likely to contribute to this decline in attitude.

  A better alignment of teaching styles, vocabulary and delivery of concepts in the mathematics teaching in the last few years of primary and first few years of secondary school will improve the transition for students and is likely to decrease the observed loss of enthusiasm and confidence.

  Increasing and improving the supply of appropriately trained mathematics teachers through short courses or upskilling is likely to help with the decline in enthusiasm and confidence, as adequately trained teachers know more about mathematics and mathematics teaching.

Main Findings

Exposure to Growth Mindset ideas and mathematical activities is effective in changing and improving students' attitudes to mathematics

- Confidence and enthusiasm increase.
- There is very strong agreement that students can learn new maths.
- Girls initially have less confidence, enthusiasm and a smaller proportion agree to having a maths brain than boys; but girls have larger gains in confidence, enthusiasm and ability to learn maths than boys.
- Following treatment, the proportions of girls and boys across the different levels of confidence, enthusiasm and ability to learn new maths are more similar than the corresponding pre-treatment proportions, and the correlation between confidence and enthusiasm are stronger post-treatment than pre.

Transition to secondary school

- The levels of confidence, enthusiasm and students' attitude to learning maths are higher in primary school.
- The levels of confidence, enthusiasm and students' attitude to learning maths drop in the year after transition to secondary school.
- Partial improvements across the years are noticeable and by Year 9 mean attitudes have increased again.

Large treatment effects

- Among the different attitudes and their changes following treatment, the increase in the level of enthusiasm is larger for girls and boys than any other change and is present in every cohort in a partition of the student data.
- The increase in the level of confidence and the increase in the ability to learn new maths are large following the intervention.
- Student cohorts starting with low proportions for maths brain show a particularly strong increase in their ability to learn maths following treatment.

Comparison of girls' and boys' attitudes to mathematics

- The distribution of girls' and boys' multivariate scores regarding their attitudes show an almost complete overlap, indicating that there is essentially no difference in attitude between girls and boys.
- There is a small difference of the means of individual attitudes between the genders, but this difference is negligible compared to the difference within the cohorts of students.

1 Introduction and Motivation

The underrepresentation of female students in Year 12 advanced school mathematics and in university mathematics degree programs is of serious concern for gender equity as well as economic reasons. Despite government efforts in recent years to increase female participation in the last years of school, the underrepresentation of women in advanced Year 12 mathematics has not changed. Although Australia witnessed an overall increase in the number of students completing Year 12, the proportion of school students who study

- Year 12 school mathematics, and in particular
- Intermediate or advanced Year 12 mathematics

and the proportion of university students who graduate with a mathematics-based degree have decreased, see Li and Koch (2017), Wienk (2022) and references therein.

From an economic perspective, industry and employer demand for mathematics graduates has been growing at a higher rate than the average rate of increase in graduates across all disciplines. The gap between demand and supply of graduates with university-level mathematics skills is widening. This gap will continue to increase unless its sources are addressed adequately. A partial solution to this skill shortage in mathematics and other numerate areas could be achieved if more women were able to fill such roles; this would simultaneously improve gender equity in the Science, Technology, Engineering and Mathematics (STEM) workforce and likely lead to more secure long-term careers and career prospects for women.

The lack of students enrolling into mathematics degrees or mathematics majors needs to be traced back to their pre-university education. Over the last decade, Australia has witnessed a declining performance of Australian school students in their mathematics achievement of the 'Australian National Assessment Program—Literacy and Numeracy' (NAPLAN), the 'Programme for International Student Assessment' (PISA), and 'Trends in International Mathematics and Science Study' (TIMSS), see Li and Koch (2017) and references therein. NAPLAN focusses on English language and numeracy-related areas and reports students' performance in Years 3, 5, 7 and 9 across every school in Australia. PISA and TIMSS report and compare the performance of Australian students with that of students from other countries. There has been an almost worldwide drop in achievement, but on the Australian scene this performance drop is larger than the average drop. This decrease is likely to be related to the lack of suitably qualified mathematics teachers which we have witnessed in Australia, the UK and other western countries. More than 15% of out-of-field teachers teach mathematics in Australian secondary school. For definition and details of out-of-field teaching in mathematics see Koch and Li (2017), Prince and O'Connor (2018), O'Connor and Thomas (2019) and references therein. The link between declining performance and lack of suitably qualified teachers can also be seen in students' disengagement with mathematics. The latter is evident in the decreasing participation in Year 11 and Year 12, but exists long before students reach the last years of school. Both the high proportion of out-of-field teachers and the disengagement of students are expected to influence students' performance and achievement negatively.

The combined effect of decreasing achievement and declining participation of students in mathematics subjects in the last year(s) of their school education on the Australian economy have led to government and industry investigations into factors behind these trends. Their focus is based on '*external*' and '*manifest*' factors such as other school subjects being less demanding, the students' (possibly justified) perception that, after scaling, higher level Year 12 mathematics subjects will adversely affect their Australian Tertiary Admission Rank (ATAR). Further, Australian universities' move away from requiring higher level mathematics knowledge—even in some degrees that rely on mathematical knowledge—has decreased the desirability of students to take higher-level mathematics subjects at school. See Wienk (2020) and Actuaries Institute (2021). The public policy statement by the Actuaries Institute aims to increase proportion and capabilities of senior student studying higher level mathematics subjects by considering a range of measures, including advanced training for educators, re-introducing mathematics pre-requisites for university enrolments, rewarding students who take higher level mathematics subjects in their ATAR, and by addressing gender-specific mathematics participation of female students.

Our emphasis is on attitudes and engagement—rather than performance and achievement. We aim to rekindle and encourage students' engagement with mathematics. For this goal in mind, we study more latent factors such as attitude towards mathematics and possible drivers for a positive change in attitude. Specifically we want to gain insight into these factors and provide at least partial answer to the following questions.

1. How are students' attitudes related to their confidence in their maths ability?
2. What factors contribute to increasing students' confidence in and attitude towards mathematics?
3. Is there a *real* difference in attitude towards mathematics of male and female students and, if so, what 'remedies' can work to address such an imbalance?

Gaining new insights into these topics could lead to new pathways for addressing the widening gap between demand and supply of mathematically skilled graduates, and revert the trend of those students who discontinue their mathematics education prematurely.

The analysis, results and recommendations we present are based on data from more than 8,000 students in Years 5–9. These data were collected from 2016 to 2019 across 120 Australian schools as part of the ChooseMaths program of the Australian Mathematical Science Institute (AMSI) and the BHP Foundation. Our analyses, findings and recommendations are concrete and easily interpretable. We expect these findings to aid the decision-making processes at state and federal government levels and anticipate that our recommendations will support educational institutions in devising steps which address crucial underlying issues in the declining mathematics participation of school students.

2 The ChooseMaths Program

The severe underrepresentation of women in the STEM workforce motivated the BHP Foundation to fund the five-year initiative ChooseMaths (CM) in partnership with the Australian Mathematical Sciences Institute (AMSI). As the central voice for Australia's mathematical sciences, AMSI has been driving a policy and advocacy agenda to achieve critical reform at key stages of the mathematics pipeline through its four programs: AMSI Schools, AMSI Research, AMSI Higher Education and APR.Intern—see amsi.org.au. From its start in mid-2015, ChooseMaths pursued its aim of increasing participation of girls and young women in STEM through a multilevel approach comprising school and university education and the workforce. The different components of the ChooseMaths program are shown schematically in the left panel of Figure 1 and described below. Central to all components is the ChooseMaths research.

The components of the ChooseMaths program.

- *Teacher professional development (PD)s:* Working closely with teachers and students in 120 schools across urban, regional and remote Australia;
- *Research lessons and student surveys:* Developing and conducting gender-related research activities in mathematics lessons for students in the 120 schools;

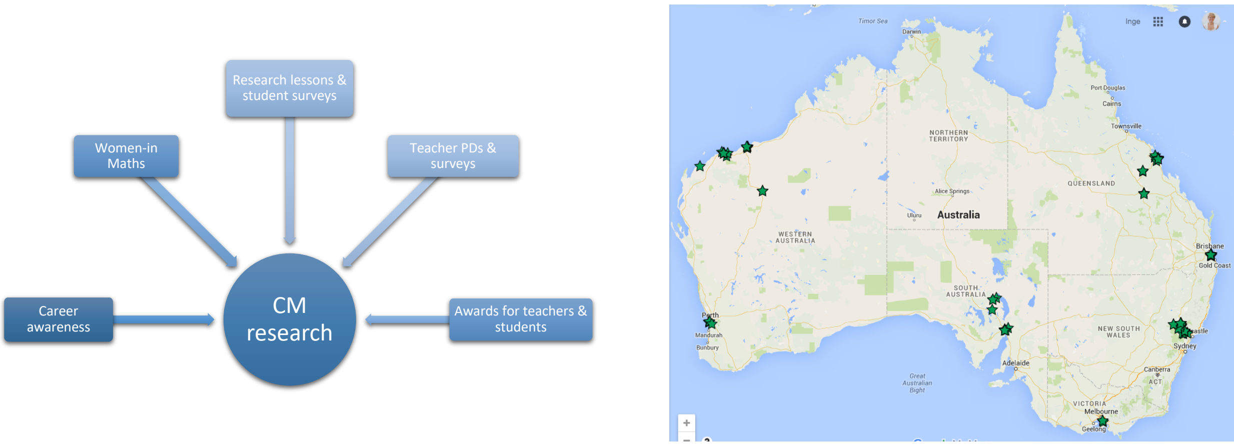

Figure 1: *Components of the ChooseMaths program and location of its schools.*

- *Women-in-Maths events:* Creating and maintaining a Women-in-Maths network and events within schools, universities and the workplace;
- *Career awareness:* Establishing positive role models and developing and promoting career awareness materials and initiatives for students, teachers and the general Australian community; and
- *Awards for teachers and students:* Celebrating the successes of mathematics teachers and students across Australia in annual award ceremonies.

The components of ChooseMaths were designed to focus on studying, evaluating and improving the *environment* in which girls and young women develop enthusiasm for and confidence in their own mathematical potential and dare to study and master challenging mathematical problems. An improved level of enthusiasm and confidence is expected to lead to higher engagement with the discipline and, as a consequence, higher achievements.

During the first few years of the program, results from ChooseMaths research showed that by creating a supportive and confidence-building environment girls in particular were able to study and achieve at a higher level than they initially aspired to. This can be attributed to the girls developing the confidence to aim higher and through their increased confidence dare more and become more successful.

We note that *improving achievement in mathematics* was not part of the brief of the ChooseMaths program, however, research relating to maths anxiety and confidence building shows the strong connection between increased confidence and higher performance and achievement, see, for example, individual contributions to the

in Koch (Editor, 2019) and individual contributions to this workshop that is covered in . The 18 staff of ChooseMaths included 11 experienced primary and secondary mathematics teachers and three researchers (two statisticians and one mathematician). The CM teachers visited and worked directly with 'their' schools in designated parts of Australia supporting and upskilling the local teachers, giving model lessons and organising mathematics related events for students and parents. The three researchers were responsible for the design, oversight and analysis of the surveys given to students and teachers, and the women-in-maths events in the schools and Australian universities.

The annual awards of prizes for the 10 best mathematics teachers and 10 best student projects showcased the highlights of the program for AMSI and the funding agency, the BHP Foundation. Mathematics teachers, primary teachers and students from all Australian schools were eligible to apply.

The main focus of this report is the 'CM research' circle shown in the left panel of Figure 1 and, more specifically, the analysis of the student surveys that the ChooseMaths teachers conducted each calendar year as part of dedicated mathematics research lessons in their schools. In the next two sections we describe these surveys and different analyses of the survey data. We present the results, provide interpretations and make recommendations based on the findings.

The right panel of Figure 1 shows the location of the schools across Australia, as indicated by the green markers on the map. The participating schools were chosen in regions of interest to and in discussion with the BHP Foundation, as a consequence we are dealing with an observational study. The participating schools cover capital cities, regional and remote regions, schools from the public and private sector and co-educational as well as single sex girls schools. The sample does not contain single sex boys schools, in line with the aims of the program. Schools were chosen as 'clusters' which, in this context, refers to a group of 4–5 schools consisting of one secondary school and 3 or 4 neighbourhood feeder primary schools to enable continuity across the school years as students move from primary to secondary school. The summary statistics of the surveys collected in the early years of ChooseMaths are described in Li and Koch (2017).

The results in Section 3 repeat some of the earlier results based on the 2016 and 2017 data, however, in this report we look at the richer data collected over the years 2016 – 2019. The analyses presented in Section 4 represent the research of the current authors.

This report restricts attention to the student surveys that were carried out as part of ChooseMaths. Complementing the student surveys, ChooseMaths together with the Australian Council for Educational Research (ACER) conducted annual surveys of teachers in participating schools. These surveys often suffered from a low response rate and the likely bias due to it; in some schools and calendar years, only 25-30% of teachers completed the surveys. The analysis of these surveys was carried out by ACER who summarised their findings in an annual report. Further findings based on the 2016-2017 data are described and discussed in Koch and Li (2017), and in Li and Sprakel (2020) and references therein for later years. We refer the interseted reader for more details to the AMSI website https://amsi.org.au/resources/program-data/.

3 The Student Surveys and Summary Statistics of the Data

Maths anxiety is more prominent among female students than among their male counterparts. This phenomenon is compounded by stereotypes and prejudices that girls cannot do mathematics as well as boys. Although there is no scientific evidence of this prejudice, the perception is widespread, see Kersey *et. al.* (2019), Levine and Pantoja (2021) and references therein. Until female students feel more confident about their mathematical potential, feel empowered to tackle the same mathematical challenges and follow mathematical pathways and professions, these perceptions are not likely to undergo a radical change. For details see Koch (2018), Koch (2019) and references therein.

Components of the ChooseMaths program focussed on the key issues of understanding and evaluating the often underestimated self-perception of female students regarding their mathematical potentials and abilities. Better insight into these phenomena will lead to new directions for building and increasing confidence of girls and young women. This report presents analyses of data which show that we, the educators and parents, can help girls and young women to become more confident in their ability and reach their potential. We begin with a description of the survey design that forms the basis of the analysis.

Visits of the CM teachers to their school clusters several times a year for typically a few weeks per cluster and per visit represented a major part of the ChooseMaths program was the . A cluster consisted of one secondary and 3-4 primary feeder schools. During these visits the CM teachers provided professional development and upskilling for teachers in primary schools and mathematical support for those teaching mathematics in secondary schools. The activities of the ChooseMaths teachers included model lessons in the class room and special classes, referred to as '*research lessons*'.

The driving force behind the research lessons was that of gaining a better understanding of students' interest and engagement in mathematics and how to increase students' awareness and enjoyment of mathematics. A typical research lesson consisted of

1. a pre-survey;
2. an interactive presentation of how our brain learns based on *Growth Mindset* ideas;
3. mathematical group activities suitable for the school year; and
4. a post-survey.

From the pre- and post-surveys we wanted to capture and evaluate the change in students' attitude to mathematics as a consequence of *treatment* or *intervention*, here items 2 and 3. Underpinning the treatment was the *Growth Mindset* approach of Boaler (2015) which students embraced with interest and enthusiasm. Some of the key elements of this approach are the *power of Yet* as in 'I have not yet learnt Pythagoras' theorem' instead of having the fixed mindset 'I can't learn Pythagoras' theorem' and the power of learning from mistakes. Ethics approval for the research lessons was obtained and renewed annually from the University of Melbourne and from relevant School authorities in the different states in Australia.

Number of students by year and year level

Year		5	6	7	8	9	Totals
2016	F	159			184		343
	M	146			103		249
2017	F	898			355		1253
	M	774			355		1129
2018	F	640	319	357	271	242	1829
	M	568	316	223	98	159	1364
2019	F	242	231	184	221	252	1130
	M	210	200	86	199	87	782
Totals	F	1939	550	541	1031	494	**4555**
Totals	M	1698	516	309	755	246	**3524**
Totals		3637	1066	850	1786	740	**8079**

Table 1: Number of students in each year level from 2016–2019 separately for girls (F) and boys (M).

The research lessons started in late 2016 with a pilot of about 600 students in Year 5 and Year 8. The survey questions are shown in Table 8 of Appendix A. Each student was given a *Plickers card* to answer the survey questions in the pre- and post-survey. The cards have unique patterns and allow four answers to multiple choice questions. Two cards are shown in Figure 9 of Appendix A. Students used the same card in the pre- and post-survey which enabled tracking of students' responses across the two surveys.

In each research lesson the ChooseMaths teacher recorded the students' answers shown on their Plickers card using a mobile phone, see Figure 10 of Appendix A. Students and teachers can see the information of the two panels. The left panel shows first names (only) of students participating in the research lesson, and the right panel tells the teacher which students have answered the question and which students have given an invalid answer (shown as a grey box).

An evaluation of the 2016 pilot survey resulted in some changes for later years. In 2017 questions 1–7 of the 2017–2019 part of Table 8 were used. The remaining questions were variably used in years 2018 and 2019. In what follows we will primarily focus on questions 3, 4 and 6 which deal with the change in confidence, enthusiasm and attitude to can learn new maths respectively. We begin with histograms relating to these questions with an emphasis on interpreting what the data tell us.

3.1 Results by gender

The histograms in Figure 2 show the key indicators of the ChooseMaths surveys: confidence, enthusiasm and ability to *can learn (new) maths* which captures the pre-survey question of having a maths brain and the post-survey question of being able to learn new maths. The results for the pre-survey (left panel of a pair of histograms, and shown in a lighter shade of a colour) are followed by those of the corresponding post-survey (in a darker colour) and this is done separate for girls, in the top row, and for boys in the lower row. For the three indicators and going from left to right within a histogram, we show the proportion of students' responses of

1. *not confident, neutral, confident, very confident* in panels 1 (pre-) and 2 (post-survey) respectively,
2. *bored, neutral, enthusiastic, very enthusiastic* in panels 3 and 4 respectively; and
3. *no, yes* in panels 5 and 6 regarding their ability to learn new maths.

Table 2 complements the histograms by providing the actual percentages in each group in the same order as in the histograms. The total numbers of students in the different panels varied slightly, since we deleted observations with missing values separately for each key indicator. In each case there are more than 7,600 records. The discussion below refers to Figure 2 and Table 2.

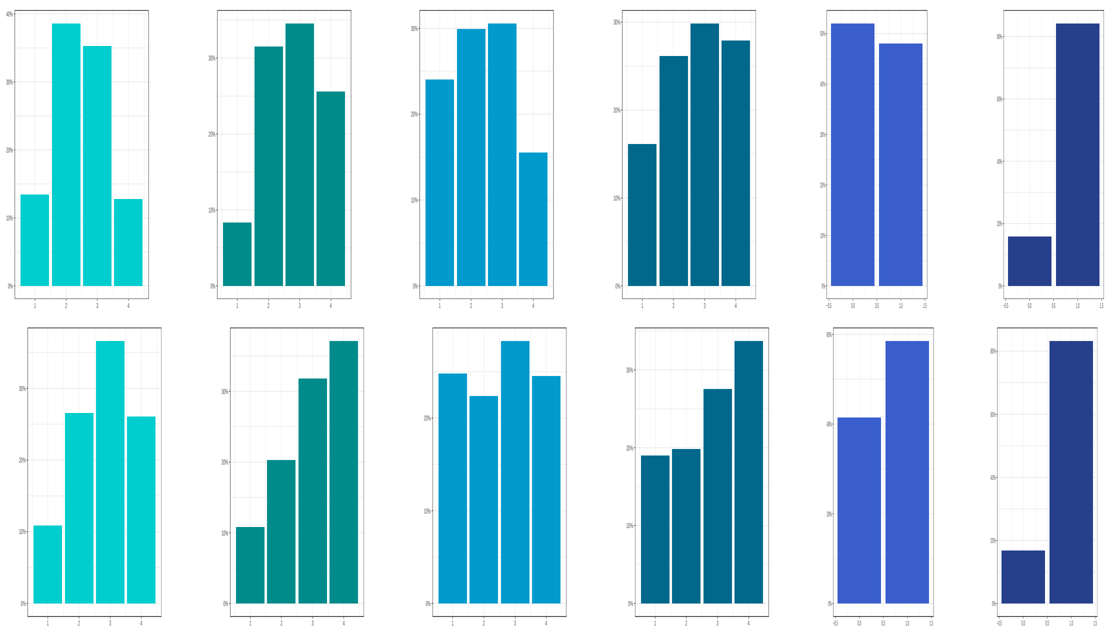

Figure 2: Row 1: Girls, row 2: boys; left to right Confidence Pre and Post, Enthusiasm Pre and Post and Can Learn Maths Pre and Post, given as percentages. See Table 2 for the percentages in each level. In each panel the levels go from lowest to highest, and from 'no' to 'yes'.

Comparison of girls and boys in the pre-survey. For the confidence plots in the left-most panel we note that more girls are in the lower confidence groups, with only half the proportion of girls in the top group. Unlike the confidence plots, the enthusiasm plots in column 3 show that the boys have an almost equal proportion in each level of enthusiasm, while the girls have a much smaller proportion than the boys for *very enthusiastic*. Column 5 shows the results of *I have a maths brain*; we notice a clear difference between the girls who show a slight majority in the left 'no' answer, and the boys with 17 percentage points majority in the 'yes' answer. These pre-survey results tell us that girls are less confident, less enthusiastic about maths than boys, and much fewer girls think they have a maths brain.

Attitudes to Maths—Pre and Post									
		Girls row 1, boys row 2 in Figure 2							
		Panels 1 & 2 in Figure 2							
Confidence	Pre	13.4	38.6	35.3	12.7	10.8	26.5	36.6	26.0
	Post	8.3	31.5	34.6	25.6	10.8	20.3	31.8	37.1
		Panels 3 & 4 in Figure 2							
Enthusiasm	Pre	24.0	29.9	30.6	15.5	24.8	22.4	28.3	24.5
	Post	16.1	26.2	29.9	27.9	19.0	19.8	27.5	33.7
		Panels 5 & 6 in Figure 2							
Can Learn Maths	Pre		52.0	48.0			41.5	58.5	
	Post		15.8	84.2			16.8	83.2	

Table 2: Changes in confidence, enthusiasm and can learn maths of girls and boys from Pre to Post, given as percentages; rows and columns use the same arrangement as the panels in Figure 2.

Comparison of girls and boys in the post-survey and treatment effect. The proportion of girls who are not confident or bored has decreased by 5 to 8 percentage points and has, in fact, fallen below that of boys. Looking at the very confident and very enthusiastic group, we note that the proportion of girls has increased by more than 12 percentage points. Although the proportion of girls in these groups is still below those of boys, the increase in confidence and enthusiasm is much larger for girls than for boys.

The change from the 'no' answer in *I have a maths brain* to *my brain allows me to learn new maths* is especially remarkable for girls: less than 50% said they had a maths brain, but after the mathematical and brain activities the proportion of girls who chose *can learn new maths* was higher than 84% and even exceeds that of boys.

Summary. The results presented in Figure 2 and Table 2 show that girls start at lower confidence and enthusiasm levels than boys, but the change affected by the treatment is larger for girls than for boys.

We do not show the responses to questions 1, 2 and 7 as there was no discernable treatment effect; about 90% of girls agreed that girls could do maths as well as boys, while only 83% of boys agreed with this statement. Question 1 is in the survey since the ChooseMaths teachers wanted to reinforce that it was alright to find mathematics hard and confusing and it was alright to make mistakes. These ideas are part of the repertoire of 'Growth Mindset' and acceptance of these facts helps with confidence building.

3.2 Results by school year and gender

Confidence. With the transition from primary to secondary school, the confidence and enthusiasm patterns change for girls and boys, and this change is more substantial than the difference between girls and boys that we saw in the previous section.

Figure 3 illustrates the changes in confidence pairs from Pre to Post (adjacent pairs in different shades), from Year 5 to Year 8 in the first and last two panels respectively, with girls in the top row and boys in the lower row. The histograms are based on 1780 girls in Year 5, 961 girls in Year 8, 1551 boys

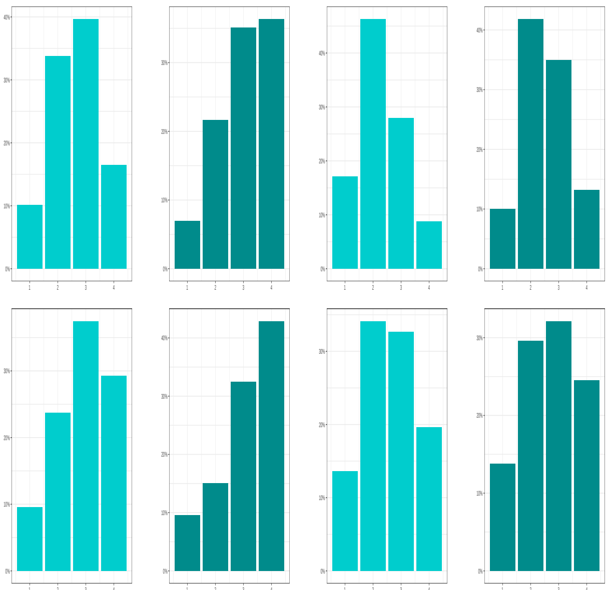

Figure 3: Confidence levels; row 1: girls, row 2: boys, left to right: Year 5 Pre and Post, Year 8 Pre and Post. See Table 3 for percentages in each level. In each panel the levels go from lowest to highest.

in Year 5, and 551 boys in Year 8. The levels of confidence are as described in Figure 2, with the corresponding percentages in each bar given in Table 3.

The histograms show that treatment is effective and the level of confidence increases, however, for girls and boys the pre-survey confidence is much higher in Year 5 than in Year 8. About 25% of boys are very confident after treatment in Year 8 compared to only 13% of girls. This is about one third of the proportion of very confident girls in Year 5 following the mathematical activities. Table 9 in Appendix B extends the information shown in Table 3 to all five years. The results indicate that effort is required to prevent the decrease in confidence especially of girls after transitioning to secondary school.

Confidence Changes for Year 5 and Year 8 by Gender

Year		Girls				Boys			
5	Pre	10.1	33.8	39.7	16.5	9.5	23.7	37.5	29.3
	Post	7.0	21.6	35.1	36.3	9.5	15.1	32.5	42.9
8	Pre	17.1	46.3	27.9	8.7	13.6	34.1	32.7	19.6
	Post	10.0	41.8	35.0	13.2	13.8	29.6	32.1	24.5

Table 3: Changes in confidence for Year 5 and Year 8 with levels from left to right: not confident, neutral, confident, very confident, from Pre to Post, given as percentages.

Enthusiasm patterns for Year 5 and Year 8 are shown in Figure 11 and in Table 10 in Appendix B in a format similar to that of Figure 3 and Table 9. The histograms look very similar to those shown in Figure 3: 39% of girls and 40% of boys are very enthusiastic following the mathematical activities, compared to 36% of girls and 43% of boys who are very confident in Year 5. In Year 8, the percentages have dropped to 17% of girls and 25% of boys who are very enthusiastic, and to 13% of girls and 24.5% of boys who are very confident.

The confidence and enthusiasm figures tell us that the gap between boys and girls at the highest level of confidence has widened more than the corresponding gap for the very enthusiastic ones. Further about 71% of girls and 75% of boys are confident or very confident in Year 5, while only 48% of girls and 57% of boys are confident or very confident in Year 8. The proportions of enthusiastic or very enthusiastic students in Year 8 are about the same, and have decreased from 68% for girls and 67% for boys from the Year 5 enthusiasm percentages.

The reduced confidence and enthusiasm which start in the first year of secondary school is of concern. Some of the reasons for this decrease are based on transition to secondary school and are well understood in the mathematics teaching community. These factors can and need to be addressed comprehensively and urgently. However, these questions are beyond the scope of this report.

Can learn new maths. In the previous section we considered the students' attitude to being able to learn new maths. As for confidence, the year-level results show that there is a drop in the proportion of students who have a maths brain and who can learn new maths after students transition to secondary school, and these levels drop further in Year 8.

Table 4 shows details of students' perception regarding learning new maths over all five years. We report Table 4 reports the percentage of students who answered 'yes' to *I have a maths brain* and to *My brain allows me to learn new maths* is given separately for girls and boys. The 'yes' percentages correspond to the second of the two bars in the two right-most panels of Figure 2. As with the confidence and enthusiasm results, the 'yes' proportions are lower for girls than for boys in Years 5–8. Remarkably, the increase in percentage points as a consequence of the intervention is considerably larger for girls than for boys, and in all years except Year 6 the percentage of 'yes' in the post survey of girls exceeds that of boys. This agrees with the results in Table 2. These results are very encouraging and efforts should be made to use them to better advantage.

Yes Responses: Maths Brain

	Year	5	6	7	8	9
Girls	Pre	55.4	54.2	35.5	38.0	44.5
	Post	88.5	88.0	81.3	74.2	86.4
Boys	Pre	63.1	57.4	53.7	48.3	54.9
	Post	87.2	88.4	80.3	68.5	82.9

Table 4: Percentages of 'yes' in each school year for have a maths brain (pre) and can learn maths (post).

Unlike the confidence and enthusiasm patterns, the Year 9 results presented in Table 4 show a strong upward trend to almost the Year 5 proportions following treatment. These results are based on 494 girls and 245 boys in Year 9 and are very encouraging. It will be interesting to examine whether this increase continues into Year 10.

Calendar years. There is essentially no difference in the survey results from one calendar year to the next. For this reason we do not show these annual results.

3.3 Transition from Pre to Post

The previous sections showcased totals of the pre- and the post-surveys for confidence, enthusiasm and can learn maths. We have seen a clear positive change in these indicators of attitudes as a consequence of the treatment, but not all students had a positive response to treatment. It is informative to investigate whether and how many students report a decrease in the post-survey.

Can learn new maths. We start with the pair of questions relating to maths brain and learning new maths as these have only two possible responses and are therefore easier to study, visualise and interpret.

Each panel in Figure 4 displays the change in the pairs (Pre: have a maths brain, to Post: can learn new maths) separately for girls in the top row and boys in bottom row and for each of Year 5 to Year 9 in the five figure panels in each row, and starting with Year 5 in the left-most panels.

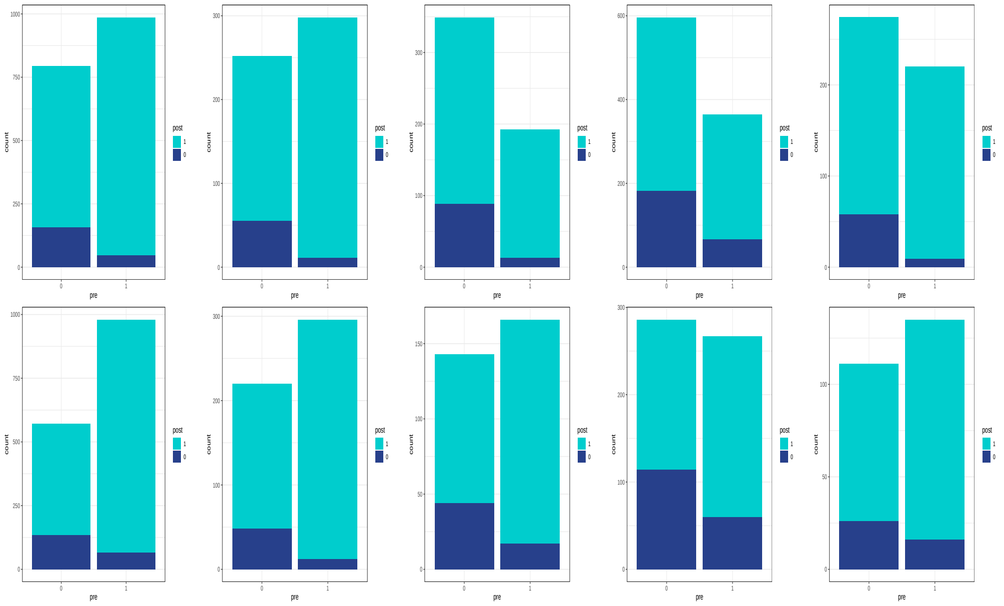

Figure 4: Can Learn Maths for girls in row 1, boys in row 2. Panels run from Year 5 (left) to Year 9 (right). Counts in the Pre are shown as heights of the bars: with 'no' in the left bar, and 'yes' in the right bar. The teal parts refer to Post and show counts of 'yes' , the blue parts give the counts of 'no'.

How do we interpret the information shown in Figure 4? The heights of the bars relate to Pre, the blue and green colours refer to Post. Consider the top left figure panel which corresponds to Year 5 girls. The left bar shows counts of students who answered 'no' in Pre and the right bar shows 'yes' counts to *I have a maths brain.* For the Year 5 girls in the top left panel, 794 girls answered 'no' and 986 answered 'yes' in the Pre. For the Post there are a total of 204 blue counts corresponding to 'no' and 1576 teal counts corresponding to 'yes' answers to *can learn new maths.* The numbers and column heights tell us that of the 794 'no' students in the pre-survey (the counts in the left bar), only 157 students shown in blue in the left bar remained a 'no' in the Post, and the remaining 637, shown in teal in the left column, changed from 'no' to 'yes' in the post-survey. For the right bar the change works the opposite way: for the 986 'yes' students in the pre-survey, 47 blue students changed from 'yes' to 'no' and the remaining 939 teal students remained 'yes' following treatment. It is very clear that more than four times the number of girls changed from 'no' to 'yes' than remained a 'no', and only 47 (or 14.8%) felt less confident in their ability to learn new maths after the treatment.

Looking at the different years which are shown in the panels going from left to right, we note that students become less confident in their ability to learn maths over the school years, however the proportion that changes from 'no' to 'yes' remains similar across the years. A comparison of girls (in the top row) and boys (in the lower row) tells us that a smaller proportion of girls than boys choose 'yes' in the pre-survey, but the proportion of girls that change to 'yes' remains larger than that of boys across the school years. This indicates the success of the treatment irrespective of the starting level.

Overall the graphs show the strong positive effect of the Growth Mindset ideas and mathematics activities on students' attitude to being able to learn new maths.

Confidence. Next we illustrate the effect of Growth Mindset related activities on confidence and enthusiasm using tables and graphical displays. Table 5 shows the transition from students' pre-confidence levels 1–4 to their post-confidence levels with 1 - not confident, 2 - neutral, 3 - confident and 4 - very confident. Each row corresponds to a level of Pre and shows the transition from the current level of Pre to levels in Post following treatment. Numbers in *italics* are counts or percentages respectively for the total of each level of Pre and Post so show the marginals. The bold **588**, for example, in the 'Girls: counts' part of the table tells us that 588 girls were not confident, so a 1 in Pre which is shown in the row Pre 1. This number corresponds to the bold **13.4** in the 'Girls: percent' part of the table. Of these 588 students only **174**, shown in (Pre 1, Post 1) felt not confident in Post. As a percentage of all level 1 Pre female students these 174 represent **29.6%**. So more than 70% of not confident female students felt more confident following the mathematical activities. The table also tells us that 267 students or 45% of the Pre 1 cohort transitioned from not confident to neutral (2), so Post 2, and 58 student or 9.9% felt very confident (4) in the Post.

A glance at the 559 very confident (4) female students in the row Pre 4 tells us that 394 or 70.5% of the cohort remained very confident, while a small 6.1% (34 students) felt not confident and transgressed to (Pre 4, Post 1) following treatment. Similar interpretations apply to the boys' tables.

Although not explicitly available from the table, the analysis showed that 37.4% of girls and 31.3% of boys reported an increase in increased their confidence following the mathematical activities, while 12.8% or girls and 16% of boys apparently lost some confidence. This indicates a clear transition to higher levels of confidence. Girls are less confident than boys in Pre as we previously observed in Table 2 and Figure 2, but a larger percentage of girls than boys change to higher levels of confidence following treatment. The first two green-shaded panels of Figure 5 show this movement graphically.

Changes in Confidence of Girls and Boys

		Girls: counts					Boys: counts				
		Post 1	2	3	4		Post 1	2	3	4	
Pre	4	34	43	88	394	*559*	42	67	121	614	*844*
	3	48	240	782	477	*1547*	66	145	570	406	*1187*
	2	110	833	558	193	*1694*	88	347	291	135	*861*
	1	**174**	267	89	58	**588**	154	99	49	49	*351*
		366	*1383*	*1517*	*1122*	*4388*	*350*	*658*	*1031*	*204*	*3283*
		Girls: percent					Boys: percent				
		Post 1	2	3	4		Post 1	2	3	4	
Pre	4	6.1	7.7	15.7	70.5	*12.7*	5.0	7.9	14.3	72.7	*26.0*
	3	3.1	15.5	50.5	30.8	*35.3*	5.6	12.2	48.0	34.2	*36.6*
	2	6.5	49.2	32.9	11.4	*38.6*	10.2	40.3	33.8	15.7	*26.5*
	1	**29.6**	45.4	15.1	9.9	**13.4**	43.9	28.2	14.0	14.0	*10.8*
		8.3	*31.5*	*34.6*	*25.6*	*100*	*10.8*	*20.3*	*31.8*	*37.1*	*100*

Table 5: Changes in confidence of girls (cols 2-5) and boys (cols 7-10); Pre totals in cols 6 and 11, Post totals in rows 6 and 11. Rows show transition in confidence from Pre to Post.

We focus on the first two panels from the left in Figure 5. They display the transition from Pre to Post regarding confidence as shades of green using the same arrangement of rows and columns as Table 5, but leaving out the totals. In the figure panels, square (p, q) refers to the percentage of students in row p and column q, with row 1 the bottom row, and column 1 the left-most column. Darker shades correspond to higher percentages. The first panel from the left refers to girls, the second to boys. In the left-most girls' panel square (1,1) corresponds to **29.6%** in (Pre 1, Post 1) and square (4,4) corresponds to the 70.5% in (Pre 4, Post 4) of Table 5. The latter square is a much darker shade of green. Returning to square (1,1) we note that square (1,2) is considerably darker than (1,1); indeed, a glance at Table 5 tells us that the percentage of students moving from not confident in Pre to neutral in Post is more than 1.5 times the size of the percentage of students who remain not confident.

With the exception of square (1,1) in the left-most panel, the diagonal squares (1,1), (2,2), (3,3)

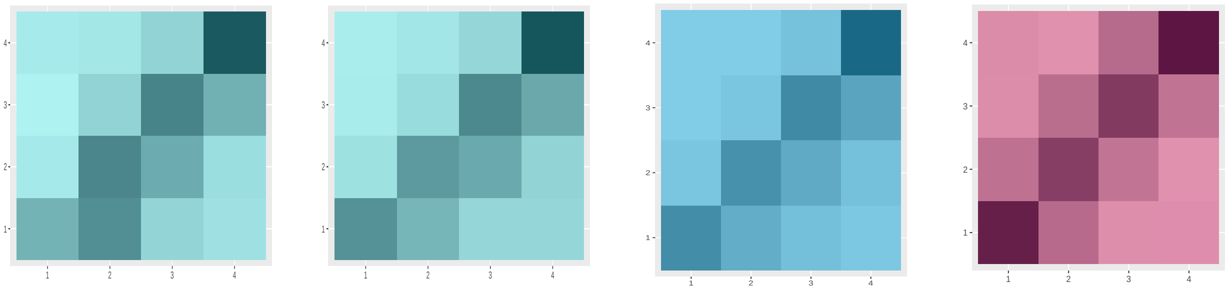

Figure 5: Changes in confidence and enthusiasm in Pre and Post corresponding to 'Girls: percent' and 'Boys: percent' in Table 5 (1st and 2nd figure panels), and to Table 6 (3rd and 4th figure panels).

and (4,4) are darker than any other squares with the darkest shades at (4,4) in each of the panels. The diagonal squares represent the percentage of students who remained at their level of confidence following treatment. It is worth noting that the percentage of students in square (4,4) is the darkest in each of the four panels, over 70% in the first and second panels. We may interpret this in the following way: the top students for Pre mostly remain at the highest level, while overall students at lower levels of confidence or enthusiasm increase their attitude towards mathematics.

Enthusiasm. The third panel of Figure 5–in blue tones–shows changes in enthusiasm for all students and the fourth panel shows the relationship of Post confidence and Post enthusiasm. Counts and percentages corresponding to these two panels are given in Table 6. In the two panels on the right we present the combined results for girls and boys, as the differences between the genders were smaller than in the two left panelswhich relate to confidence. The interpretation of the transition in enthusiasm in the third panel is the same as that described for the confidence panels. In the first three panels the colour shades range from 0% to 75%. In the right panel shades range from 0% to 65%. We will comment further on the right-most panel below.

Relationships Enthusiasm and Confidence

		Enthusiasm Post: counts						Enthusiasm Post Counts				
		1	2	3	4			1	2	3	4	
Pre	4	92	89	206	1150	*1537*	Conf	195	173	492	1527	*2387*
	3	133	247	1195	763	*2338*	Post	225	526	1244	638	*2633*
	2	224	967	605	294	*2090*		525	972	491	153	*2141*
	1	961	531	290	187	*1969*		462	163	68	73	*766*
		1410	*1834*	*2296*	*2394*	*7934*		*1407*	*1834*	*2295*	*2391*	*7927*
		Post: percent						Percent				
		1	2	3	4			1	2	3	4	
Pre	4	6.0	5.8	13.4	74.8	*19.4*	Conf	8.2	7.2	20.6	64.0	*30.1*
	3	5.7	10.6	51.1	32.6	*29.5*	Post	8.5	20.0	47.2	24.2	*33.2*
	2	10.7	46.3	28.9	14.1	*26.3*		24.5	45.4	22.9	7.1	*27.0*
	1	48.8	27.0	14.7	9.5	*24.8*		60.3	21.3	8.9	9.5	*9.7*
		17.8	*23.1*	*28.9*	*30.2*	*100*		*17.7*	*23.1*	*29.0*	*30.2*	*100*

Table 6: Changes in confidence of girls (cols 2-5) and boys (cols 7-10); Pre totals in cols 6 and 11, Post totals in rows 6 and 11. Rows show transition from Pre-level after treatment.

Observe that in the first three panels of Figure 5 the colour shades to the left of the diagonal are lighter than those to the right. This tells us that the movement to less confidence or less enthusiasm is smaller than the transition to higher confidence/enthusiasm levels, and agrees with our previous comments that 31.3% of girls increased in confidence while only about one third lost some confidence.

We may interpret the positive change as the treatment effect and conclude that Growth Mindset and other mathematical activities have been effective in increasing confidence and enthusiasm of students.

Relationship of confidence and enthusiasm levels. The fourth panel of Figure 5 and the right half of Table 6 show the relationship between Post confidence and Post enthusiasm for all students. As both confidence and enthusiasm are from Post treatment, the interpretation differs from those of the other panels. The rows correspond to the different levels of confidence and each row shows the spread of enthusiasm across a given confidence level. Note that the diagonal squares going from (1,1) to (4,4) are still darkest. They express the percentage of students with the same level of confidence and enthusiasm, for example, of the 2387 very confident (4) students, 1527 (or 64%) are very enthusiastic. Regarding the 2633 confident (3) students, 1244 (or 47.2%) are enthusiastic (3), 638 of the confident students are very enthusiastic and 526 are neutral. The numbers indicate that, although there is an overlap of 53% of students who have the same level of confidence and enthusiasm, for many students their levels of confidence and enthusiasm do not agree. A look back at the histograms of Figure 2 confirms this point.

The overall information of the Pre confidence/enthusiasm relationship is similar to that shown here, and for this reason we are not including it. However, the cohorts that have the same level of confidence and enthusiasm are smaller than in Post; a total of 46.7% of students have the same level of Pre confidence and enthusiasm, and only 54.5% of very confident students are also very enthusiastic.

3.4 Interpretation of results from summary statistics

The figures and tables of the summary statistics for gender, school year and transition from Pre to Post tell us that exposure to Growth Mindset ideas and mathematical activities is effective in changing and improving students' attitudes to mathematics as can be seen by

- Confidence and enthusiasm increase; and there is very strong agreement that students can learn new maths.
- Girls initially have less confidence, enthusiasm and maths brain than boys; but girls have larger gains in confidence, enthusiasm and can learn maths than boys.
- Following treatment, the proportions of girls and boys across the different levels and attitudes are more similar than the corresponding pre-treatment proportions, and the correlation between confidence and enthusiasm are stronger post-treatment than pre.

Of concern are the statistics relating to the transition to secondary school and the associated drop in attitudes. In particular,

- The levels of confidence, enthusiasm and attitude to learning maths are higher in primary school;
- The levels drop in the year after transition to secondary; but
- Partial improvements across the years are noticeable and by Year 9 mean attitudes have often increased again.

It is essential that we address the causes for this drop which is, in part, a consequence of the different teaching styles in primary and secondary schools, but can be as basic as different notions are used for the same mathematical item in primary and secondary school. Other factors that are likely to contribute to the drop in attitudes are the relatively high proportion of out-of-field teachers who typically teach at the junior end of secondary school. They and their students would benefit from suitable upskilling for the teachers in mathematical knowledge and paedagogy.

4 Cluster Analysis of the Survey Data

In this section we look at patterns that are present in the data and characterise groups of students who share certain behaviour patterns or attitudes to mathematics. To find such patterns we consider all relevant variables of the data simulateously so studying the multivariate data which extends the single variable or pairs of variable analyses of the previous section. For notational convenience we abbreviate the quantities or variables of interest and write

- G0 and G1 for the question: girls and boys can learn maths equally well;
- C0 and C1 for confidence levels;
- E0 and E1 for enthusiasm levels; and
- M0 and M1 for maths brain and can learn new maths respectively.

For each pair of variables, say (G0, G1), 0 refers to Pre and 1 to Post. The variables G0, G1, M0 and M1 take the values 0 and 1; the variables C0, C1, E0 and E1 have four possible values: 1, 2, 3 and 4. To make the range of the last four variables more comparable to that of G0, G1, M0 and M1, we replace the four responses for G0, G1, M0 and M1 by 0, 0.5, 1 and 1.5 respectively, so 'old' 1 becomes 0, and 'old' 4 becomes 1.5. The ordering of the responses is not affected by this transformation. In the analyses presented in this section, we only use these transformed values and, for notational convenience, refer to them as the students' responses which were, in fact, A, B, C or D.

4.1 Visualisation of responses for many variables

We consider two contrasting visualisations of multivariate data which provide complementary insight and information.

Parallel coordinate plots. We begin with graphical representations for eight-dimensional data. We list the eight variables, here in the order G0, G1, C0, C1, E0, E1, M0, M1, on the horizontal axis as in both panels of Figure 6. Next we show the value of each variable directly above it, with the vertical axis displaying the range of the values, here 0.4 to 1. For example, the value of 0.73 for C0 is shown in light blue in the left panel. Then we connect the values—going from left to right—by a line which results, for example, in the light blue line in the left panel. In our graphs the line segments connecting Pre and Post values are meaningful: they explicitly show the change that occurred from Pre to Post. In contrast, the line segments from say C1 to E0 have no actual interpretation and serve no purpose other than the reader's convenience in tracing a graph across all variables. These lines connecting individual points are especially helpful if multiple graphs are shown in a single panel as in the two panels in Figure 6. We refer to graphs of this form as *parallel coordinate plots.* The values at the variables are sometimes referred to as outcomes or responses.

The left panel of Figure 6 contains two graphs which correspond to the means for the girls, shown in light blue, and the means for the boys, shown in the darker blue. For each variable, the mean score is calculated across the responses of this variable for all girls, and, respectively, for all boys. We note that the means of the girls and boys are very similar, but the boys' means are higher than the girls' means for all variables other than the pair (G0, G1). The higher means for girls in G0 and G1 may not surprise, however, it is reassuring to know that more than 50% of the boys think that girls and boys can do mathematics equally well.

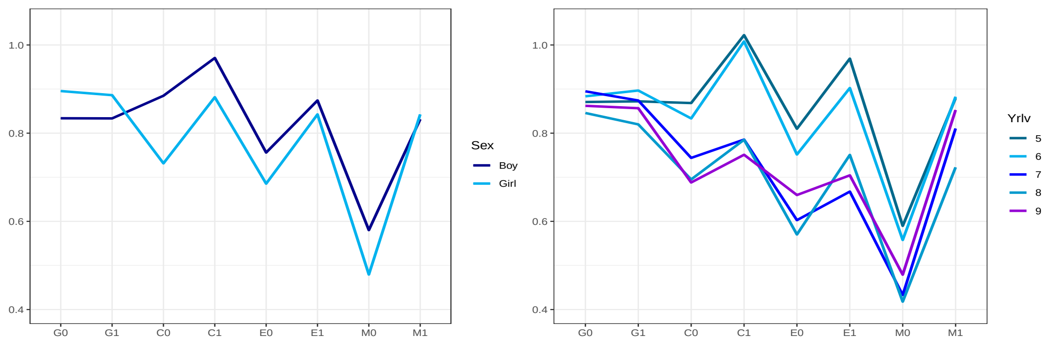

Figure 6: Means of responses to 8 variables; means over girls and boys (left panel) and over year levels (right panel).

Hypothesis tests for a difference in mean would show a significant difference for all variables, primarily because of the large sample size, and hence not tell us very much. In contrast, looking at the change in means following the treatment is more informative: For the pairs (C0, C1) and (E0, E1) we see a big increase from Pre to Post with a relatively larger percentage increase in the Post values for girls than for boys. These results are consistent with our findings in the previous section, but also provide evidence for much decreased gap in confidence and enthusiasm following treatment.

For the pair (M0, M1) the treatment results in even more remarkable results: Pre mean of the girls lies well below that of the boys, however, the Post mean of girls is higher than that of boys, and shows the big change that has taken place among the girls as a consequence of the treatment.

The right panel of Figure 6 shows mean graphs over the year levels 5 to 9 for the eight variables G0, ...,M1. Each graph is shown in a different colour for easier interpretation. A clear drop in the mean values of all variables other than (G0, G1) is visible as the students enter secondary school in Year 7. Although well known to educationalists, this drop in confidence, enthusiasm and can learn maths is of concern and needs to be addressed, but this task is beyond the scope of this report. Suffice it to note that by Year 9 (shown in purple in the figure) students' perception of being able to learn new maths has increased considerably, compared to Years 7 and 8, and has almost reached the high mean levels which we observed in Years 5 and 6 of primary school for M1. The Year 9 graph suggests that over time targeted maths activities can be effective in affecting and improving secondary school students' attitudes to mathematics.

Figure 6 shows the means for groups of students separately for all eight variables. In Section 4.2 we show graphical displays for all students as part of a multivariate analysis. The focus will be to detect differences between groups of students beyond the differences in the means of girls and boys or year levels and to display the observations in the different groups in two-dimensional visualisations.

Principal component plots. In the parallel coordinate plots in Figure 6 we summarised the data by considering means over groups of students. For each student we now combine their eight responses into 1, 2 or 3 quantities which capture the key information contained in the data. Principal component analysis (PCA), which is driven by variability in the data, achieves this goal: the PC scores are weighted combinations of all eight variables. They are ranked by their contribution to the overall variance in the data, with the first PC scores contributing most. The weights of individual variables in the PC scores provide information about the relative importance of each variable and enable us to find the quantities that differ most within the multivariable data.

Because of the ranking of the PC scores by their variance, we can use the first few and most important ones to summarise the multivariate data visually. We represent each student by their first and second (or first and third) PC scores, and plot these two scores as points in a 2-dimensional plot. We refer to such plots as PC1/PC2 (or PC1/PC3) score plots. Figure 7 shows such plots. We will discuss and interpret these plots in detail in the next section. For details on PCA and visualisations with PC scores see Sections 2.2 and 2.3 of Koch (2013). In the score plots in Section 4.2 we will be using transparency to express higher and lower numbers of observations with the same scores.

4.2 Cluster patterns

The student population is not homogeneous, but consists of cohorts with different attitudes to mathematics. To gain insight into the composition of the different groups or cohorts in the data, we partition the students using the eight variables listed at the beginning of Section 4. In the following analyses we include those students only who have no missing values in the eight variables; this results in 7457 students. We divide the data into groups of students with similar values in the eight variables, so without using other variables such as gender or year level. The aim is to find meaningful interpretations of the resulting groups. We use k-means clustering to partition the data and consider a number of different values for the number of clusters, here called k. For details on k-means clustering see Section 6.3 of Koch (2013).

Since we do not know the true number of clusters or distinct cohorts in the data, it is natural to

1. start with a small number of clusters, typically $k = 2$;
2. interpret the resulting cohorts for this k;
3. increase the number of clusters by one, explore the pattern arising from $k+1$ clusters and relate the new pattern to previously obtained patterns;
4. repeat step 3 while the new pattern remains meaningful; and
5. stop when the new pattern does not contain additional useful insights.

For a given number of clusters which the user chooses, an observation, here a student, is assigned to the single cluster whose other students are most similar to the current student. Once all observations have been allocated to the k clusters, we visualise the resulting patterns using parallel coordinate plots of the k cluster means, similar to the means over groups shown in Figure 6, and we display individual observations in PC1/PC2 and PC1/PC3 score plots. The results of the cluster analyses can be seen in Figure 7. The left column of figure panels shows parallel coordinate plots of the cluster means for 2, 3, 4 and 5-means cluster arrangements, starting with two clusters in the top panel. The middle and right columns of figure panels show PC1/PC2 and PC1/PC3 score plots respectively for the number of clusters in the left panel of the same row. The PC1 scores are shown on the vertical axis for easier comparison with the cluster mean coordinate plots. The means of the clusters are superimposed in the PC score plots as red triangles.

The parallel coordinate plots of cluster means and the PC score plots yield complementary information. For easier comparison across rows and columns of panels, we use the same colours, green and blue in the top row, for the two cluster means and the observations belonging to the green and blue clusters respectively. A quick glance at the columns shows that, as we increase the number of clusters from k to $k + 1$ (and go to the next row of figure panels), we keep the colours from the previous k clusters and introduce a new colour for the emerging cluster mean and its observations. For the 3-cluster arrangement in the second row of figure panels, the cluster mean shown in the (darker) blue represents the new cluster. The other two cluster means look very similar to those of the panel above since a large proportion of their students are the same as in the previous row.

It is worth pointing out that the distribution of points in the PC score plots in the middle and similarly in the right columns do not change as we move from k to $k + 1$ clusters. The reason is that we are plotting the *same* scores each time. What does change in these PC score plots is the colour of some observations, as they change cluster membership, for example from the green cluster in the 2-cluster arrangement to the darker blue cluster in the 3-cluster arrangement. By this colour change the PC score plots show which observations change cluster when we go from k to $k+1$ clusters.

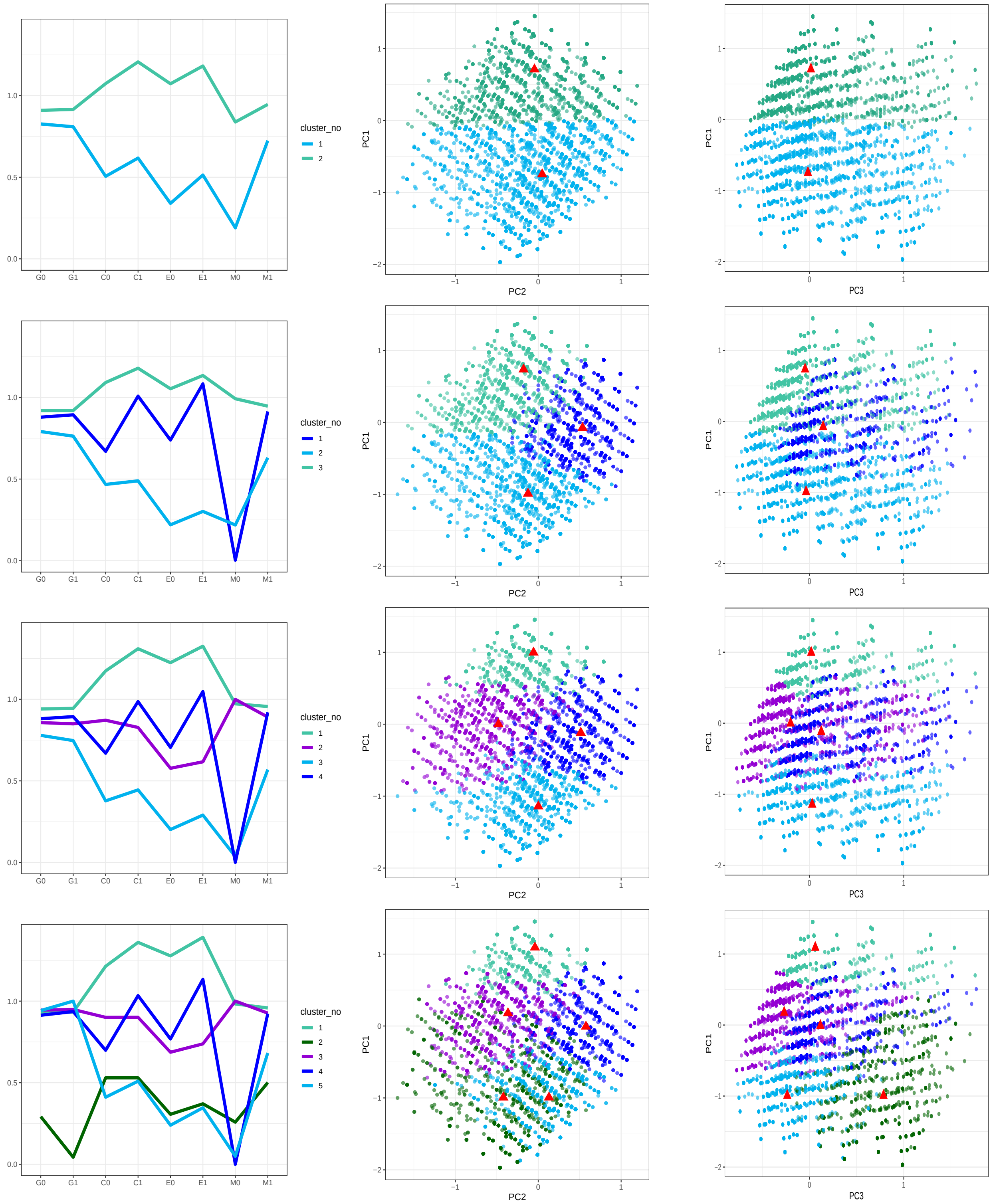

Figure 7: Means of clusters (left column) and PC score plots of observations into clusters varying from 2-means to 5-means clusters with PC1/PC2 (middle) and PC1/PC3 score plots (right column).

Comparisons of the cluster membership in different rows allows us to trace the movement of observations from one cluster to another as the number of clusters increases and this leads to insightful interpretations of the different cohorts.

In the last two paragraphs of Section 4.1 we referred to the weights associated with each variable in the PC scores and their relative importance of the variables. For PC1 the enthusiasm variables E0 and E1 have the largest absolute weights, M0 and E1 contribute most to PC2, and G0 and G1 contribute most to PC3. These contributions are related to variance, so tell us that within the multivariate data the Pre and Post levels of enthusiasm are most distinct, followed by the response to maths brain and, again, Post enthusiasm which tells us that Post enthusiasm, E1, is the one of most interest. The fact that on average Post enthusiasm scores increased in all cohorts may be regarded as a positive effect of the mathematical activities.

4.3 Interpretation of cluster cohorts

Before interpreting the results of individual panels shown in Figure 7, we note that as a consequence of the treatment

1. the mean enthusiasm increases for every cluster in every k-cluster arrangements with k=2, 3,4 or 5—as seen by the positive slope from E0 to E1 in every graph shown in the parallel coordinate plots;
2. the mean confidence increases—as seen by the positive slope from C0 to C1 in all cluster arrangements with the exception of 'purple' cluster in the 4- and 5-cluster arrangements;
3. the mean change from 'have a maths brain' to 'can learn maths' (M0 to M1) is mostly very positive, and is particularly strong for cohorts with a low M0 mean; and
4. there is little difference between the mean graphs of girls and boys—as the means in Figure 6 show.

In each of the k-cluster arrangements the proportion of students belonging to the (top) green cluster is larger than that of any other cohort in the cluster arrangement depicted in the same row. This green cohort consists of students with higher or highest scores in confidence, enthusiasm and have a maths brain. With the increase in the number of clusters, the size of individual clusters decreases. In the case of the green cohort, the green cluster decreases from over 51% in the 2-cluster arrangement to 25% in the 5-cluster arrangement. The the mean values of the green cohort along the eight variables increase, especially for E1, since the observations with lower values join a cluster whose mean they are closer to. Analogously, the mean values for the light blue cluster tend to decrease as the number of clusters increases.

A visual comparison of the 2 to 5-cluster arrangements tells us that the majority of observations in a k-means cluster arrangement remain part of their cluster in the transitions from k to $k+1$ clusters. This behaviour of the observations is not always met in other data, here it allows a consistent interpretations of and insight into different cohorts of students regarding their attitude to mathematics. We next look at such interpretations in more detail.

Results for 2 clusters. In the 2-cluster arrangement in the top row of Figure 7, the clusters capture the higher green and respectively the lower light blue confidence/enthusiasm groups. The means of both groups demonstrate an increase in confidence and enthusiasm following treatment. The green cluster in the PC score panels is slightly larger (51%) than the light blue one and has a girl/boy split of 53/47, so, proportionately, more boys than girls belong to this green cluster as boys represent about 40% of the total population. The two score plots in each row are based on different PC scores on the horizontal axis, for this reason they look different and different information can be gleaned from them as we shall see.

Comparison of 2 and 3-cluster arrangements. The means of the 2-clusters in top panel are very similar to the green and the light blue cluster means in the 3-cluster arrangement. The new (darker) blue cluster is the smallest of the three clusters, containing about 22% of students. The middle panel in the second row shows that the new blue cluster arises from a wedge of the previous clusters: students with larger PC2 values and low to mid-range PC1 scores form this new cluster, which combines the lower end of the green cluster and the higher end of the light blue cluster. The PC1/PC3 scores in the right panel shwo more explicitly that this new blue clusters is located in the middle of the PC1 range and mostly in the middle of the PC3 range. The parallel coordinate plot of the three cluster means reveals that the new blue cluster contains observations with very low M0 values. This tells us that the new blue cluster contains students from the previous 2 clusters who do not think they have a maths brain, but whose confidence in their maths ability has increased dramatically during treatment—a very encouraging result.

Results for 4 clusters. More than 2/3 of the observations of the new purple cluster in the 4-cluster arrangement come from the green (top) cluster, 5 observations or 0.3% moved to it from the blue cluster, and the remaining observations transitioned from the lowest light blue cluster of the 3-cluster arrangement. The actual numbers are shown in Table 7 which details the movement from the 3-cluster to the 4-cluster arrangement. We may interpret the purple cohort as reasonably confident, with higher confidence than enthusiasm, that is, students who are less engaged in mathematics. Treatment seems to have less effect on this cohort of confident students. The right panel—showing PC1/PC3 scores—tells us that green observations with negative PC3 scores or with PC3 scores between 0.5 and 1, so the less enthusiastic students, are part of the purple cluster. Although in this view the purple cluster appears to consist of two disjoint groups, a comparison of the first and second panel of Figure 12 tells us that this is not the case. In the second panel from the left of Figure 12 all observations except those from the purple cluster are shown in a very light grey, making the purple ones more visible and showing that the purple observations consist of one region.

3 versus 4 means clustering

	green (1)	blue (4)	lt. blue (3)	purple (2)	row tots
green (2)	2290	1	0	1100	3391
blue (1)	40	1607	1	5	1653
lt. blue (3)	0	104	1853	456	2413
col tots	2330	1712	1854	1561	7457

Table 7: Comparison of 3- and 4-means cluster arrangements; see Figure 7 for colours.

Comparison of 4 and 5-cluster arrangements. The light blue cohort has split into two clusters: over 66% of the observations in the new olive cluster stem from the light blue one in the 4-cluster arrangement and another 20% come from the purple cluster, whose mean increased after 'shedding' these observations. The students in the new olive cluster are distinct from students in any other cluster in that they show low agreement with 'girls and boys can do maths equally well'. Further, the level of agreement did not increase following treatment. The students in the new olive cluster start at a low level of confidence and enthusiasm and the increase following treatment is not large in either of them. Similar to the purple cohort, the olive cohort seems to consist of students who are not engaged, but may also include students who have been left behind.

The olive group has lower mean confidence and mean enthusiasm than the purple group, and similar small increases in both quantities following treatment. However, unlike the purple group, there is a noticeable increase in the mean M1 from the mean M0 scores of the Pre. Such an increase is not present in the purple cluster. Overall, the olive cohort is small and covers just below 10% of the students: 12% of the boys and 8% of the girls, so relatively more boys are disengaged than girls.

The PC1/PC2 score plot in the bottom row does not reveal enough information about the transition to the olive cluster. A likely reason is that the relative contributions of G0 and G1 to PC1 and PC2 are negligible and small respectively. The two quantities G0 and G1, which distinguish this cohort from all others, are the strongest contributors to PC3. In the PC1/PC3 view in the bottom right panel we note the olive observations characterised by low PC1 and high PC3 scores. This is the part that originated from the light blue cluster in the 4-cluster arrangement in the panel above. Figure 12 in Section 6.3 of Appendix C repeats the 4- and 5-cluster PC1/PC3 panels of Figure 7, but re-displays both by highlighting the new clusters in their colours and using transparency with light grey for all other observations. Such a view reveals these clusters more clearly and shows which parts of the data they moved away from in the split into 4 and 5 clusters respectively.

Gender distribution. In the 2-cluster arrangement the green cluster of the more confident and enthusiastic students consists of about 50% of boys, a larger proportion than the 40% of boys present in the sample. This suggests that, on average, relatively more boys have higher scores than girls, a fact, which is reflected in the higher means in the left panel of Figure 6. A natural question arising form this difference in the means is whether boys generally higher means than girls. To find an answer to this question we study the distribution of students' PC scores, and particularly their PC1 and PC2 scores. These scores provide some insight into the question whether boys and girls have similar attitudes to mathematics.

In the PC1/PC2 score plots of Figure 7 we used different colours to represent the disjoint clusters. Now we want to distinguish girls' and boys' scores by different colours. The left panel of Figure 8 shows the girls' and boys' scores in rose and blue respectively. The right panel repeats the rose scores of girls, and transparency with light grey for the boys's scores. This allows a clearer view of the spread of the girls' scores across all scores. Overall there is strong agreement between the distribution of girls' and boys' scores as indicated by the spread of the two sets of scores. A careful inspection reveals that there are more boys' scores with low PC1 and PC2 values and similarly with high PC1 and PC2 scores. This tells us that the boys' scores are more spread out than the girls scores. The means of the two groups are very close in the PC1/PC2 view as noticeable by the two red triangles.Since the PC1/PC2 scores provide evidence about variability in the data, the large overlap of the girls' and boys' scores tell us that there is very little difference between girls' and boys' enthusiasm for and confidence in mathematics.

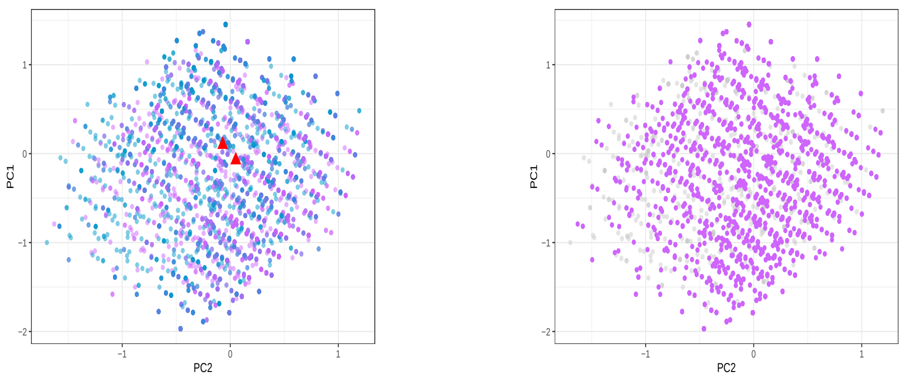

Figure 8: Distribution of PC1/PC2 scores of girls (rose) and boys (blue in the left panel and light grey with transparency in the right panel) showing the almost complete overlap of the two groups.

4.4 Findings and interpretation of results from multivariate analysis

The findings arising from the multivariate analysis enhance and extend the results obtained in the previous section. Maths activities have a positive effect on enthusiasm, confidence and ability to learn maths. Our results provide encouraging evidence that attitudes to mathematics can change with the right type of treatment and mathematical activities. The multivariate cluster analysis further shows that

- Among the different attitudes and their changes following treatment, the increase in the level of enthusiasm is larger than any other change and is present in every cluster.
- Other large effects are the increase in the level of confidence and the increase in the ability to learn new maths. The latter is particularly strong for cohorts that started with very low values for 'I have a maths brain'.
- There is no real difference between the girls' scores and the boys' scores. The almost complete overlap of the distribution of girls' and boys' scores supports the hypothesis of 'no difference in attitudes'.

The increase in (mean) enthusiasm is evidenced as the largest contributor to the PC1 scores which is present in every cluster, independent of whether the data are divided in 2, 3, 4 or 5 clusters.

Although the mean values in enthusiasm, confidence and learn new maths are higher for boys than girls both in Pre and Post, their almost identical distribution of PC1 and PC2 scores is strong evidence for 'no real difference'.

In the multivariate cluster analysis we divided the data into 2 to 5 clusters. We did not attempt to find the 'correct' number of clusters, and the analyses indicated that no single arrangements stands out as protraying the correct split. Instead, we acquire different insight and information from each of the cluster arrangements:

- For two clusters the data split into student groups with higher and lower levels on all of enthusiasm, confidence, and learning new maths.
- For the three cluster arrangement the new cluster consists of more girls than boys and is characterised by studnets with low maths brain values, that is, low confidence in their ability prior to the mathematical activities. The previous two clusters remain almost the same, but shrank in size.
- For four clusters the new cluster mostly draws from the top and bottom clusters and contains students with lower enthusiasm levels and high values for I have a maths brain.
- The smallest fifth cluster consists primarily of students from the lowest cluster who
  - do not agree that girls and boys can do mathematics equally well, and who
  - show a strong increase in their ability to learn new maths following treatment.

5 Summary, Conclusions and Future Directions

Motivated by the underrepresentation of young women in mathematics secondary school and univerversity education and in the STEM workforce we studied girls' and boys' attititudes to mathematics with the aim or achieving a new insights and a better understanding into differences between the genders which might contribute to or explain some of the reasons and causes for this underrepresentation.

Towards the end of Section 1 we raised questions relating to students' attitude towards mathematics including the issue of gender differences of students' attitudes. Below we summarise the findings of our analyses in response to these questions.

- The analyses show a strong positive correlation between increased confidence and more positive attitude of students regarding their ability to learn new maths. This is demonstrated in the increase in the level of confidence and the much higher proportions of 'yes' votes to can learn new maths following treatment. These results show that students can and do change their attitude to mathematics when their confidence increases.
- Students are responsive to Growth Mindset ideas and embrace the power of Yet; they respond positively to information on how their brain works, to learning that their brain can learn new maths, and to learning that they can apply this knowledge to appropriate mathematical activities. Such directed activities appear to contribute strongly to increasing students' enthusiasm and confidence and, more generally, their attitude to learning form mistakes and being able to learn new mathematics.
- There is no real difference between the attitudes to mathematics of female and male students, as evidence by the distributions of individual results which are almost the same. In particular, the gap in confidence, enthusiasm and ability to learn new maths have decreased considerably following treatment. Furhtermore, the mean differences between girls and boys are negiligible compared to the much larger differences observed between year levels and between cohorts found in the cluster patterns.

Regarding future directions, there are three main areas the analysis highlighted and recommendations for addressing these areas.

- Confidence building and growth mindset ideas into the mathematics curriculum at various year levels.
  Students, and especially female students, can be motivated by and respond positively to mathematical activities which are designed to increase their enthusiasm for and confidence in their mathematical ability. As a consequence of increased enthusiasm and confidence students attempt more challenging mathematics tasks and experience success with these.

  Recommendation: Integration of mathematical activities into the mathematics teaching and careful assessment of the effect on students' attitudes.
- Supporting specific cohorts of students.
  There are small proportions of students at all year levels who experienced only a very marginal increase in enthusiasm and confidence, including a reasonably confident cohort of students which typically consists of more boys than girls.

  Recommendation: Investigation of student cohorts that are 'left behind' and development of strategies and opportunities to re-engage them with mathematics.
- Transition from primary to secondary school.
  Of concern is the decrease in attitudes of students when they enter school school and during the first years at secondary school. The different teaching modes in primary and secondary school, and potentially also the teaching by out-of-field teachers in the early years of high school are likely to contribute to this decline in attitude.

Recommendation: Provision of programs or modules for primary and secondary teachers to interact and decrease the differences in teaching modes.

6 Appendix

6.1 Appendix A: Survey questions and data collection

Survey Questions

	Pre-Survey 2016	**Post-Survey 2016**	
1	Maths is useful in many areas in everyday life	Maths is useful in many aspects of life and careers	Y/N
2	Girls can do maths as well as boys	Girls can do maths as well as boys	Y/N
3^1	I like to work on maths problems with others	I like to work on maths problems with others	Y/N
3^2	I like to learn something that needs maths	Maths will help me find a job	Y/N
4	I like doing maths	I like doing maths	Y/N
5	I have a maths brain	My brain allows me to learn new maths	Y/N
	Pre-Survey 2017–19	**Post-Survey 2017–19**	
1	It's okay to feel confused about maths	It's okay to feel confused about maths	Y/N
2	Girls and boys can learn maths equally well	Girls and boys can learn maths equally well	Y/N
3	When I think about maths I'd describe myself as: not confident, neutral, confident, very confident	After the lesson today I feel: same	A-D
4	When I think about maths I feel: bored, neutral, enthusiastic, very enthusiastic	After the lesson today I feel: same	A-D
5	Sharing tasks with others helps me understand maths better	Working with others on the task today helped me	Y/N
6	I have a maths brain	My brain allows me to learn new maths	Y/N
7	Thinking about maths I like: working on maths activities, finding out	After the lesson today I like: how we learn, both, neither (all 4 for both)	A-D
8	I like doing maths	I like doing maths	Y/N
9	My brain allows me to learn new maths		Y/N

Table 8: Survey questions for pilot in 2016; followed by 2017-19 survey questions. 3^1 was used for the Year 5 students in 2016, 3^2 was used for the Year 8 students instead. In 2017 questions 1 – 7 were used, the remaining questions were added in the later years.

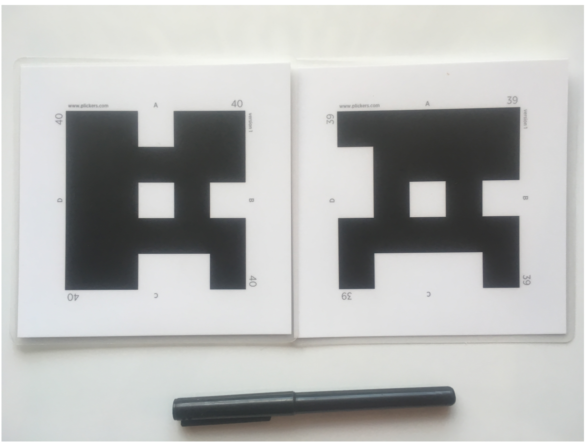

Figure 9: *Two examples of Plickers cards.*

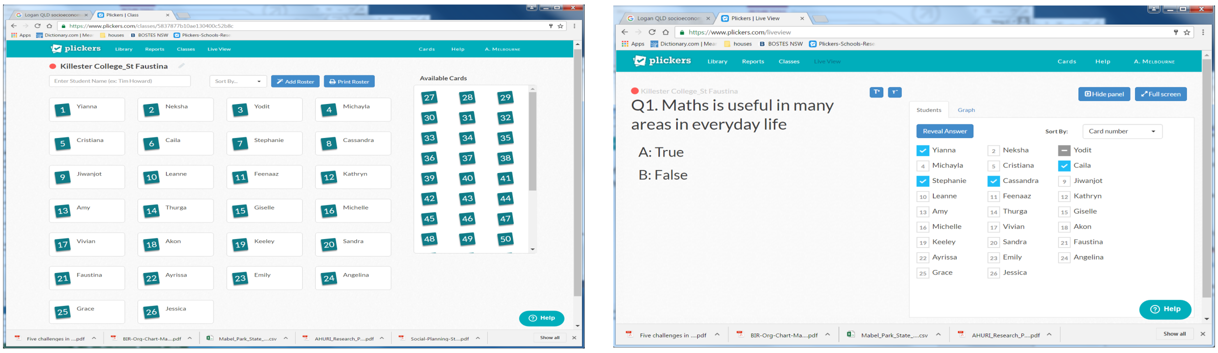

Figure 10: *Collecting data with Plickers cards (left) and from individuals (right).*

6.2 Appendix B: Confidence and enthusiasm changes by year and gender

Confidence changes by Year and Gender

Year		Girls				Boys			
5	Pre	10.1	33.8	**39.7**	16.5	9.5	23.7	**37.5**	29.3
	Post	7.0	21.6	35.1	**36.3**	9.5	15.1	32.5	**42.9**
6	Pre	11.1	35.7	**36.2**	16.9	12.8	24.4	**38.0**	24.8
	Post	7.3	24.4	33.0	**35.3**	7.4	20.5	29.7	**42.4**
7	Pre	16.1	**42.3**	32.5	9.1	10.0	25.9	**38.2**	25.9
	Post	11.7	**39.1**	33.4	15.8	18.1	23.3	**29.4**	29.1
8	Pre	17.1	**46.3**	27.9	8.7	13.6	**34.1**	32.7	19.6
	Post	10.0	**41.8**	35.0	13.2	13.8	29.6	**32.1**	24.5
9	Pre	19.0	**41.3**	33.6	6.1	10.2	36.2	37.0	16.7
	Post	8.1	**49.6**	33.6	8.7	11.0	32.1	**37.8**	19.1

Table 9: Changes in confidence by school year with categories from left to right: not confident, neutral, confident, very confident. Largest proportion in bold.

Enthusiasm changes by Year and Gender

Year		Girls				Boys			
5	Pre	18.1	26.6	**34.5**	20.8	20.5	20.9	**30.3**	28.3
	Post	11.3	21.26	29.0	**38.6**	15.2	17.3	27.5	**40.1**
6	Pre	23.1	26.4	**30.7**	19.8	23.8	24.4	25.8	**26.0**
	Post	14.0	20.7	30.4	**34.0**	18.6	22.1	25.4	**33.9**
7	Pre	31.6	**34.1**	25.3	9.0	**30.1**	23.3	27.8	18.8
	Post	27.5	**31.6**	27.3	13.8	**27.2**	24.6	25.2	23.0
8	Pre	**33.5**	32.7	25.0	8.8	**35.1**	22.6	26.4	15.8
	Post	19.4	31.2	**32.4**	17.0	25.2	19.6	**30.1**	25.2
9	Pre	22.1	**35.8**	30.8	11.3	27.3	**28.6**	27.8	16.3
	Post	18.4	**37.9**	30.4	13.4	22.4	27.3	**32.7**	17.6

Table 10: Changes in enthusiasm by school year with categories from left to right: bored, neutral, enthusiastic, very enthusiastic. Largest proportion in bold.

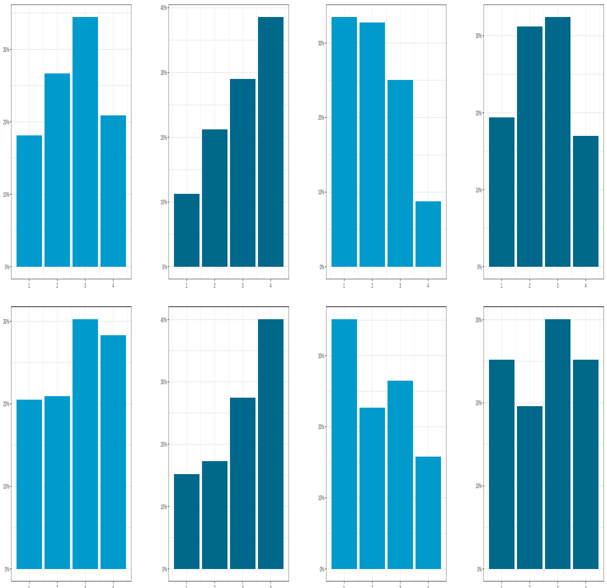

Figure 11: *Enthusiasm categories; row 1: girls, row 2: boys, left to right: Year 5 pre and post, Year 8 pre and post. See Table 10 for percentages in each category.*

% of 'blue' followed by 'green' in each bar of Figure 2

Year	5		6		7		8		9	
					Girls –					
'No'	19.8	80.2	21.8	78.2	25.2	74.8	30.5	69.5	21.2	78.8
'Yes'	4.8	95.2	3.7	96.3	6.8	93.2	18.1	81.9	4.1	95.9
					Boys					
'No'	23.4	76.6	21.8	78.2	30.8	69.2	39.9	60.1	23.4	76.6
'Yes'	6.6	93.4	4.1	95.9	10.2	89.8	22.5	77.5	11.9	88.1

Table 11: *Corresponds to Figure* **??**

6.3 Appendix C: Distribution of 4 and 5 clusters

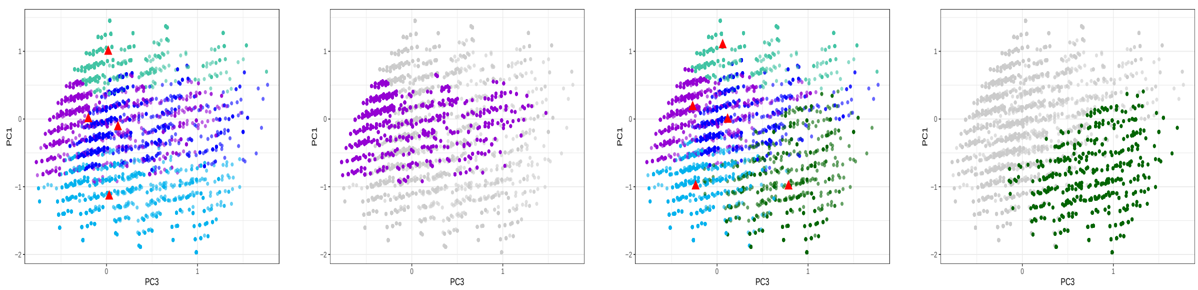

Figure 12: Clusters in a PC1/PC3 view showing 4 and 5 cluster arrangements with parts of the data in light gray, low transparency for better visualisation of the purple and olive clusters.

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