C3L EDUCATION CATALYST REPORT Nº. 7

A data summary report on the impact of a gamified computer aided design program on the spatial reasoning and attitudes of primary school students

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1. **Theory-informed**
2. **Collaborative**
3. **Meaningful**
4. **Scalable**
5. **Real-time**
6. **Sustainable**
7. **Aligned**
8. **Iterative**

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Centre for Change and Complexity in Learning (C3L)
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EXECUTIVE SUMMARY

Makers Empire is a gamified 3D computer aided design app that supports the development of design thinking and real-world problem solving in K-8 learners. Many of the interactions within the program engage spatial reasoning, a necessary skill in STEM careers.

In a partnership between Makers Empire and UniSA Catalyst— a project that seeks to support innovation in schooling by providing the multi-level, multi-scale data required to understand change in complex educational settings— this report describes trends in spatial reasoning skills and attitudes about STEM from Year 5-7 students who have participated in the Makers Empire program.

After participating in the Makers Empire program, students showed increased spatial reasoning skills, decreased anxiety about STEM subjects, and a 'closing gap' between females' and males' spatial reasoning skills and attitudes about STEM.

Over the course of the Makers Empire program, there was a significant increase in three spatial reasoning skills: spatial orientation, spatial visualisation and mental rotation.

The Makers Empire program also appeared to improve students' attitudes towards digital and design technologies, foster appreciation of the creativity involved in design thinking, and decrease anxiety students felt about STEM. Together, this indicates that the Makers Empire program may be encouraging positive feelings towards STEM and design thinking.

Interestingly, improvements to spatial reasoning skills were even more pronounced in female students. At the same time, there was also a significant improvement in girls' self-efficacy—that is, they believed in their own abilities more—which is an important factor in STEM engagement.

This suggests that the Makers Empire program may be working to close the gap between females' and males' spatial reasoning skills and attitudes about STEM. It might also mean that girls are particularly responsive to the program, highlighting a potentially influential design choice within the program itself.

Skill growth was also particularly rapid among students who scored below average on spatial reasoning skills tests prior to the program, suggesting the Makers Empire program may also engage students that wouldn't normally choose to engage.

This report supplies a brief overview of the baseline data collected. Clearly, the benefits of the collaborative research detailed in this report are evident, but there are many more potential impacts of gamification worthy of further investigation and research.

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INTRODUCTION

Makers Empire is a gamified 3D computer aided design (CAD) app that supports the development of design thinking and real-world problem solving in K-8 learners. This engaging virtual 'Maker Space' prompts students to solve challenges and share their creations with other learners to build educational communities. As many of the interactions within the program engage spatial reasoning, UniSA Catalyst investigated the possible development of both the students' attitudes towards STEM and their spatial thinking.

Spatial reasoning refers to the students' capacity to think about the relationships between shapes and objects within environments, whether they be virtual or real. Training in this capacity has been shown to improve student achievement in STEM (Uttal et al., 2013), and has particular influence on mathematical performance (Hawes et al., 2022). Traditionally, spatial reasoning within primary classrooms has been developed with manipulatives and static diagrams, but virtual 3D environments provide the opportunity to extend thinking through cleaner, more flexible and extensible features (Dokic et al., 2021). Additionally, CAD programs such as Makers Empire can provide the ability to dynamically adapt, split and recombine objects therefore providing educational affordances beyond the average classroom. Consequently it was hypothesised that involvement with the Makers Empire program would benefit spatial reasoning development.

Beyond thinking capacities, attitudes towards STEM have an important role in determining student cognitive and affective engagement with the subjects. They filter the skills students identify as important and frame the subsequent learning. Makers Empire has identified a particular mandate to 'be fun' as well as educational and hence this study also explores any attitudinal changes in the students over the course of the study.

DATA COLLECTION

School Contexts and Background

Three schools were involved fully in this study - Pouched Frog College, Red Eyed Tree Frog Primary School and Spotted Green Frog Primary School.

Pouched Frog College is a non-selective co-educational Catholic R-12 school situated in Metropolitan South Australia. The Spatial Reasoning Instrument (SRI) was administered at the start and end of the Maker's Empire program run in Term 3 of 2021. The Student Attitude Survey (SAS) was administered at 3 points during the study.

Red Eyed Tree Frog Primary is a non-selective co-educational government primary school situated in Metropolitan South Australia. The Spatial Reasoning Instrument (SRI) was administered at the start and end of the Maker's Empire program run in Term 2 of 2021. The Student Attitude Survey (SAS) was administered at 3 points during the study.

Spotted Green Frog Primary School is a non-selective co-educational government primary school situated in Metropolitan South Australia. The Spatial Reasoning Instrument (SRI) was administered at the start and end of the Maker's Empire program run in Term 3 of 2021. The Student Attitude Survey (SAS) was administered at 2 points during the study.

		SAS			**SRI**
		Year 5	Year 6	Year 7	All Years
Pouched Frog College	Female		28		25
	Male		38		41
	Total		66		66
Red Eyed Tree Frog Primary School	Female		9	4	8
	Male				10
	Total		9	4	18
Spotted Green Frog Primary School	Female	20	16	10	46
	Male	21	15	15	58
	Total	42	31	25	104
Other Deidentified Schools	Total	42	106	29	155
	Grand Total		**177**		**343**

Table 1: Number of student participants by school, year group, instrument, and gender

The Focus Sample Group

The focus sample group was sourced from students who were of an age to do the spatial reasoning test (11-13 year olds). Additionally, spatial reasoning data was sourced from 6 other deidentified school totalling 155 students. Two instruments were adopted in this project to measure students' spatial reasoning performance and their attitudes towards STEM subjects at school. Detailed in Table 1 are the numbers in each focus school.

Students

Students from Years 5, 6 and 7 from three schools contributed data to this study. The Spatial Reasoning Instrument (SRI) was administered in class and marked by the classroom teacher prior to the first session with Makers Empire. This assessment was repeated towards the end of the study. The School Attitude Survey (SAS) was administered online prior to the students' involvement in the program and again towards the end of the study. The number of students who contributed data via each of these instruments is shown in Table 1.

Measuring Spatial Reasoning

The Spatial reasoning instrument (SRI) developed by Ramful et al. (2017) is a paper based test measuring student attainment in the subskills of spatial orientation, spatial visualisation and mental rotation. There are 10 multiple choice questions per subskill mixed throughout the 30-question test.

Figure 1: An example Spatial Orientation question from the SRI

Spatial orientation

Spatial orientation has strong links with navigation. It refers to the way people mentally position themselves in the world and is key to the important mathematical understanding of proportion and ratio. A well-developed understanding of spatial orientation also contributes to estimations of measurement, perspective and describing the spatial relationships between different shapes and objects.

Harris et al. (2021) recently identified spatial orientation as a particularly important, but understudied, predictor of mathematical performance.

Spatial visualisation

Spatial visualisation relates to imagining multi-step transformations within an object or shape. This can include combining, splitting, transforming or scaling objects, which are often needed in CAD.

Spatial visualisation is an especially difficult—yet important—construct for students. Rittle-Johnson et al. (2019) identified links between young children's spatial visualisation development and ability to create patterns. This indicates the importance of spatial visualisation in the early development of mathematical skills, although the influence of this spatial capacity wanes as the content increases in complexity (Harris, 2021).

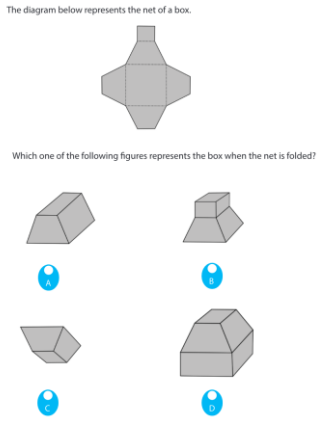

Figure 2: An example Spatial Visualisation question from the SRI

Mental rotation

Mental rotation is often one of the most natural elements of spatial reasoning and has consequently been extensively researched. Geometry clearly benefits from the ability to mentally rotate 3D objects because it ensures different aspects of shapes and objects can be compared. This subskill is also highly important when constructing new designs within the CAD environment.

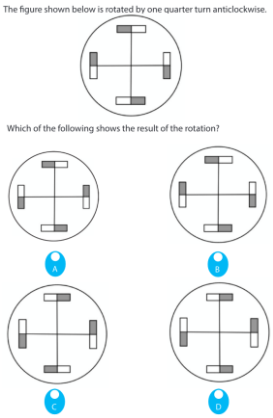

Figure 3: An example Mental Rotation question from the SRI

Measuring Student Attitudes

The School Attitude Survey was developed from the School Science Attitude Survey (Kennedy et al., 2016) and measures a student's attitudes towards their subjects against nine Attitudinal Factors. These factors are:

- Anxiety
- Creativity
- Difficulty
- Enjoyability
- Intentions
- Relevance
- Self-Efficacy
- Career Usefulness
- Personal Usefulness

Student attitude ratings are reported on a visual analogue scale from -50 to +50 (Figure 4). The Attitudinal Factors Anxiety and Difficulty are both reverse keyed.

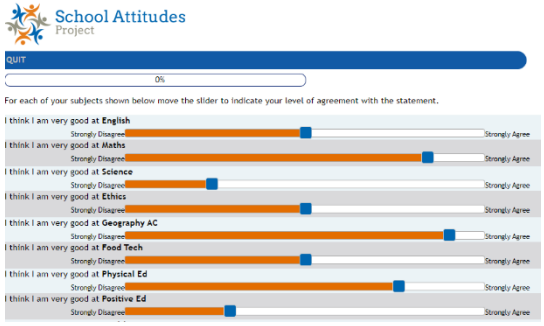

Figure 4: Screenshot of the School Attitudes Survey

A student's mean attitude rating for each attitudinal factor across all of their subjects is calculated and is known as the student's Composite Attitude Rating (CAR). A student's CAR can be thought of as a measure of their average attitude to the academic aspects of school as a whole.

Subject Attitude Ratings (SAR) are then calculated by subtracting a student's CAR for a specific attitudinal factor from their raw attitude rating for the individual subject for that same attitudinal factor. A SAR could therefore theoretically fall in the range -100 to +100. A student's SAR can be thought of as a measure of their attitudes towards a single subject area in comparison to their attitude towards school as a whole.

Attitude ratings are processed into a graphical form that shows the mean values and standard deviations for each of the nine attitudinal factors (Figure 5). In an Attitudinal Profile a high rating represents the ***desired*** outcome. Therefore, a positive rating for anxiety represents a low-level of anxiety (relaxed students are the desired outcome) and a positive rating for difficulty represents a low-level of difficulty (students who are not struggling is the desired outcome). The box indicates the interquartile range (the middle 50% of students), the solid horizontal line indicates the median, and the whiskers indicate the lesser of the extreme rating or 1.5 times the interquartile range. Any black dots indicate students whose reported ratings lie outside the normal distribution.

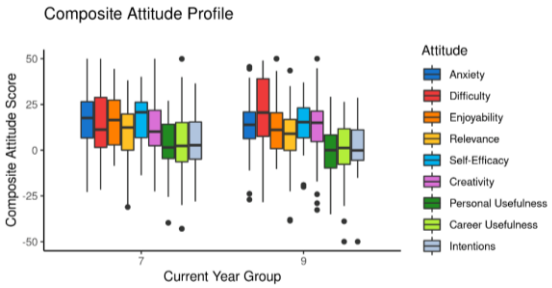

Figure 5: Sample Attitude Profile

RESULTS

Overall Spatial Reasoning Results

To identify any changes in spatial reasoning skills that occurred over the Makers Empire program, the SRI pre-test and post-test scores of the whole cohort of students (the focus schools and the deidentified schools) were analysed (Figure 6).

Overall, there was a significant increase in SRI total scores after students participated in the Makers Empire Program

A repeated measures t-test for the whole sample showed a statistically significant increase in SRI Total scores with an increase in average score from 15.79 (SD = 5.27) to 17.54 (SD = 5.60), $t(340) = 8.373$, $p < .001$.

Analyses were also conducted on each of the individual focus schools. Changes in SRI Total score at Red Eyed Tree Frog School were not significant at the 95% confidence level, and this is most likely due to their low participant numbers. Pouched Frog College showed small yet statistically significant increases in mean SRI Total score from 17.48 (SD = 4.14) to 18.20 (SD = 5.25), $t(65) = 1.931$, $p = .029$. Spotted Green Frog School ($M_{Pre} = 14.97$, SD = 5.03 to $M_{Post} = 17.02$, SD = 5.21, $t(102) = 5.626$, $p < .001$) and the Other Schools group ($M_{Pre} = 15.60$, SD = 5.80 to $M_{Post} = 17.88$, SD = 5.84, $t(152) = 7.341$, $p < .001$) both had clear and statistically significant growth.

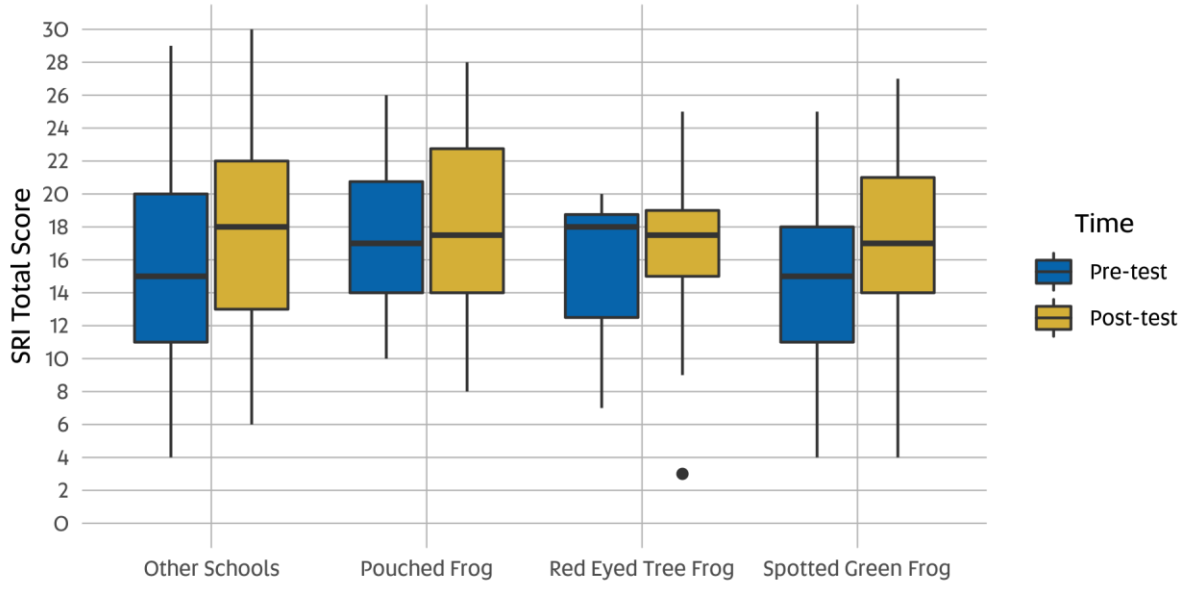

Figure 6: SRI development over the duration of the Makers Empire Program

Examining the SRI subskills reveals some interesting patterns (Figure 7). Spatial Orientation showed growth across almost all schools with an average change in subskill score across all students of 0.43 points to 7.55 out of 10 (SD = 2.06), t(339) = 4.37, p < .001. This finding is particularly interesting as recent research indicates that this subskill is important for achievement in mathematics (Harris et al., 2021).

Mental rotation showed statistically significant growth across three of the four school groups, Pouched Frog College being the exception. Across all students, the mean Mental Rotation score rose from 4.79 (SD = 2.43) to 5.67 (SD = 2.52), t(339) = 7.967, p < .001.

Of the three subskills, students found the Spatial Visualisation measure the most difficult. Nevertheless on average students' Spatial Visualisation scores rose by 0.49 points to 4.36 (SD = 2.04) and this was statistically significant, t(339) = 5.38, p < .001.

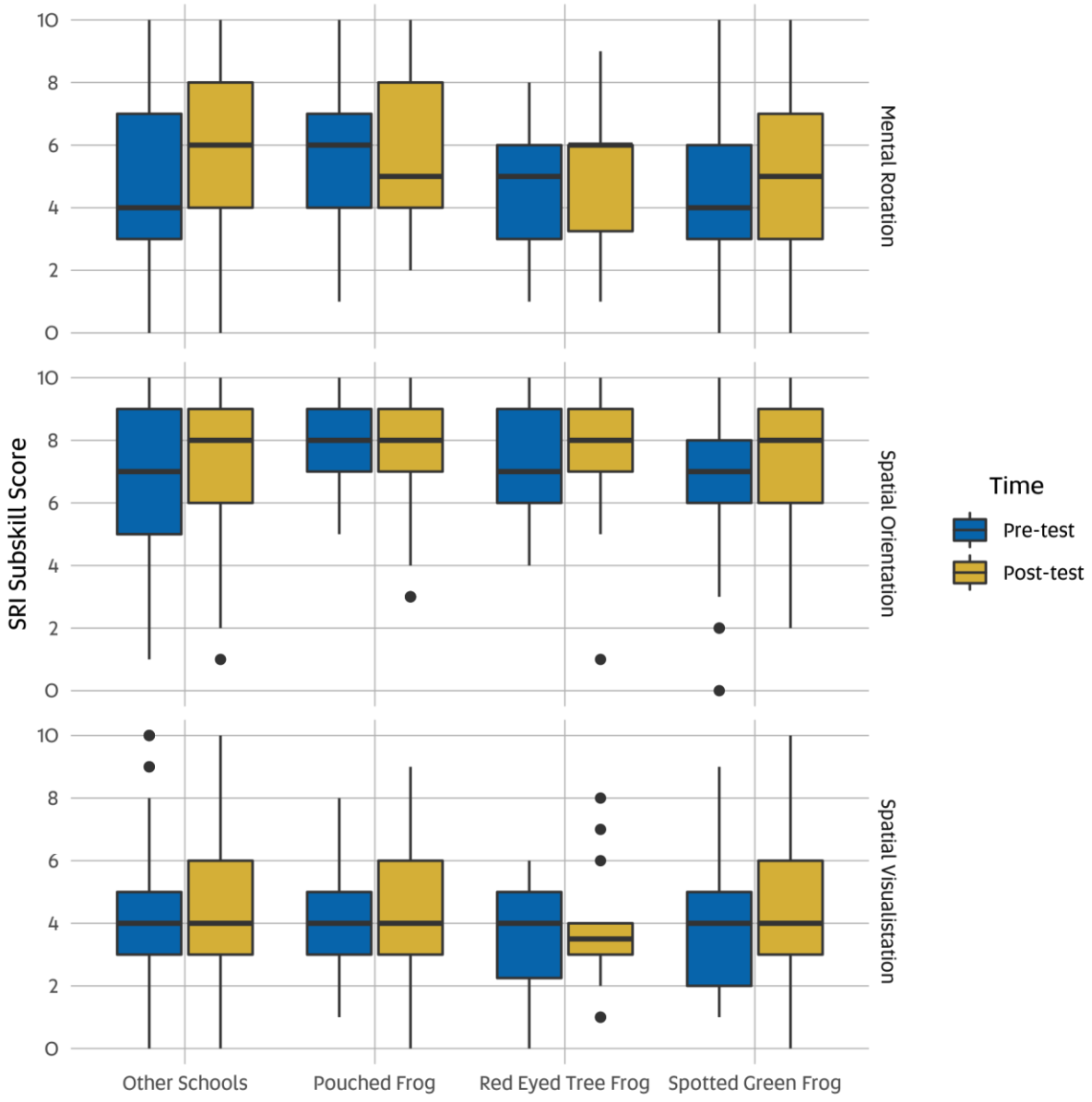

Figure 7: Changes in SRI scores for each subskill by school.

shows a significant difference between male and female students in the Mental Rotation SRI subskill with female students scoring significantly lower than their male peers prior to the Makers Empire program. This difference is also seen in the Total SRI score although this is not as statistically significant. A similar analysis on the post-test data shows no statistically significant differences between the genders on any subskill or overall.

Table 2 shows the growth of SRI Total score for all students in in the sample. Growth is calculated as the difference between the post-test score and the pre-test score. It is clear to see that in almost all cases, the mean growth was positive. Furthermore, growth showed an observable gender effect with female students showing a mean growth of 2.08 points (out of 30) (SD = 3.68) compared to male students (M = 1.60, SD = 3.65). However, this change is not statistically significant.

This observable difference in growth between the genders is also present in each of the SRI subskills (Figure 9) but in each case the growth does not meet the criteria for statistical significance.

It is clear that the additional growth in the SRI subskills demonstrated by the female students in this study has contributed to closing the gap originally seen between males and females prior to engaging with the Makers Empire program

SRI Scale	Mean Score (SD)					
	Female	Male	Difference (Male – Female)	*t*	*df*	*p*
Mental Rotation	4.40 (2.37)	5.12 (2.43)	-0.72	2.750	327.43	.006
Spatial Orientation	6.92 (2.20)	7.28 (2.03)	-0.36	1.591	313.43	.112
Spatial Visualisation	3.88 (2.06)	3.84 (1.70)	+0.04	0.180	293.41	.857
Total	15.19 (5.44)	16.25 (5.10)	-1.06	1.821	315.56	.070

Table 2: Differences between mean scores of the SRI subskills and totals between genders prior to the study

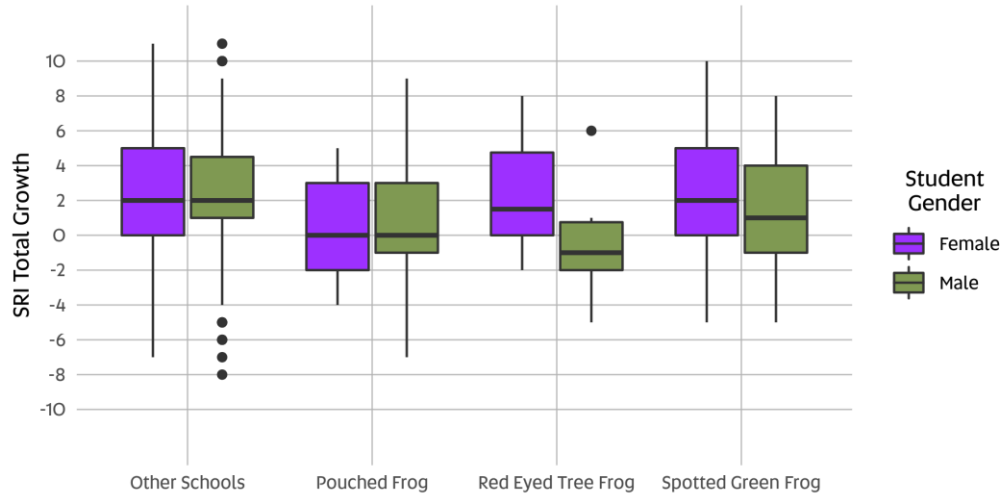

Figure 8: Growth in Total SRI score by school and student gender

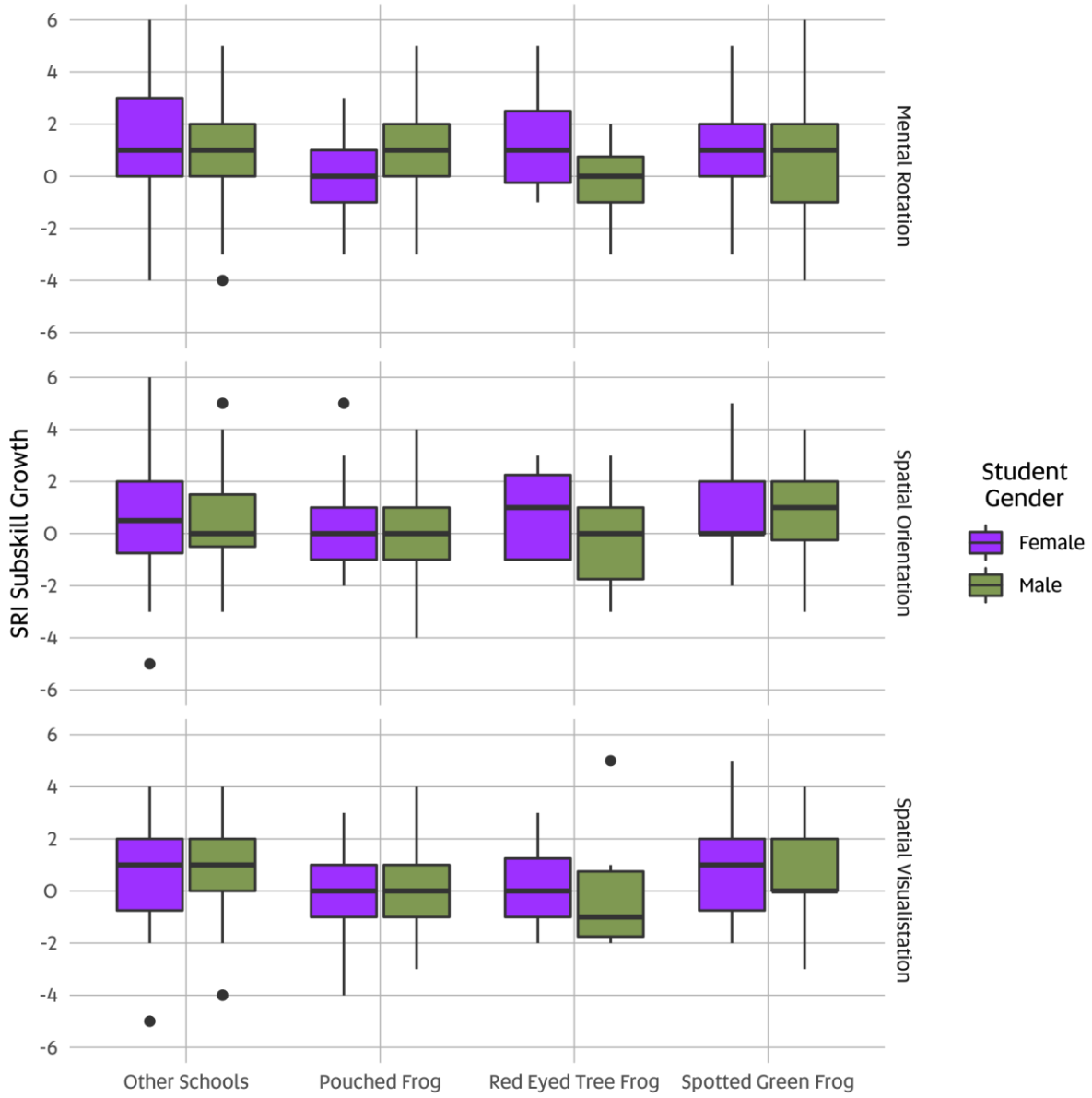

Figure 9: Growth in SRI subskill scores by school and student gender

There is a wide range of scores seen in the SRI results in Figure 7 and Figure 9. We therefore analysed the nature of the trajectories for different types of students present in the sample. This analysis revealed that there are four distinct types of trajectory (Figure 10).

- Trajectory A (31.8% of students) – these students begin with SRI scores below average and show the most rapid growth over time.
- Trajectory B (30.9% of students) – these students begin with SRI scores above average and show slow growth over time.
- Trajectory C (20.6% of students) – these students begin with SRI scores much below average and show little growth over time.
- Trajectory D (16.8% of students) – these students begin with SRI scores much above average and show slow growth over time.

These data clearly show that a student's SRI Total score growth trajectory is dependent on their initial SRI score prior to the Makers Empire program. Interestingly, student gender or school socio-economic index did not have any statistical impact on which trajectory a particular student might be found.

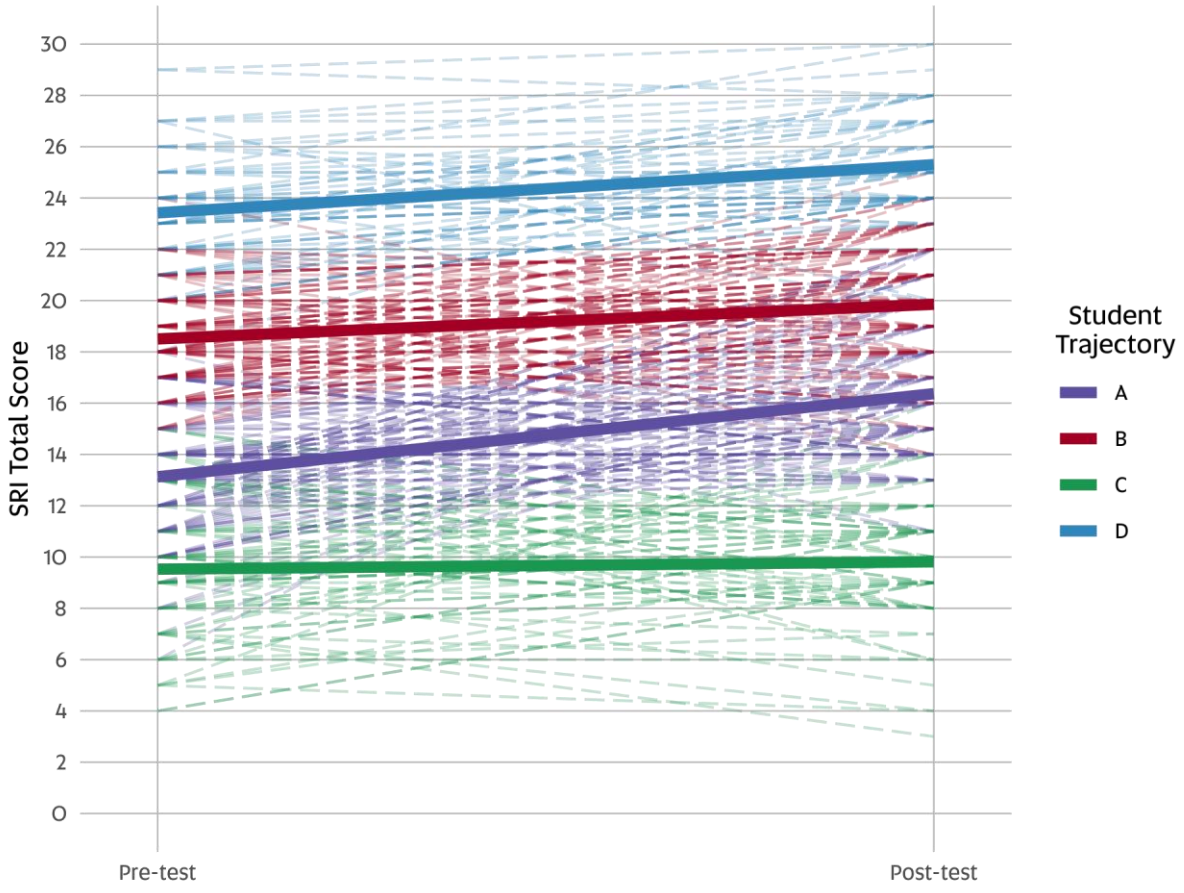

Figure 10: Student growth trajectories observed in SRI Total scores

School Attitude Survey Results

Figure 11 shows students' attitudes towards their school subjects as a whole at the outset of the study. This figure can be thought of as the initial baseline against which any changes can be considered. All students report having mostly positive attitudes towards school in general with a mean attitude score of 8.3 (SD = 17.1). The most positive attitudes towards school were found to be Enjoyability (M = 12.4, SD = 15.4) and Anxiety (M = 12.8, SD = 15.4). These data indicate that students find school generally enjoyable, and they are not anxious about their studies (N.B. Anxiety and Difficulty are reverse scored so positive scores in these areas indicate desirable outcomes). The attitudes with the lowest ratings for the cohort were Personal and Career Usefulness.

This indicates that students—on average--considered they had an equal number of school subjects that were useful to their personal careers futures as subjects that would not be useful.

In general, this positive attitude profile suggests that the students in this study were likely open to the ideas and approaches promoted by the Makers Empire program.

Across all attitudinal constructs, except Difficulty, female students rated themselves more positively than their male peers. However, these differences were only statistically significant for Personal usefulness (females rated themselves 5.8 points higher than male students, t(171) = 2.18, p= .031), Career usefulness (female students rated themselves 5.3 points higher than male students, t(175) = 2.24, p = .027), and Intentions to continue with study (females rated themselves 6.7 points higher than male students, t(169) = 2.55, p = .012).

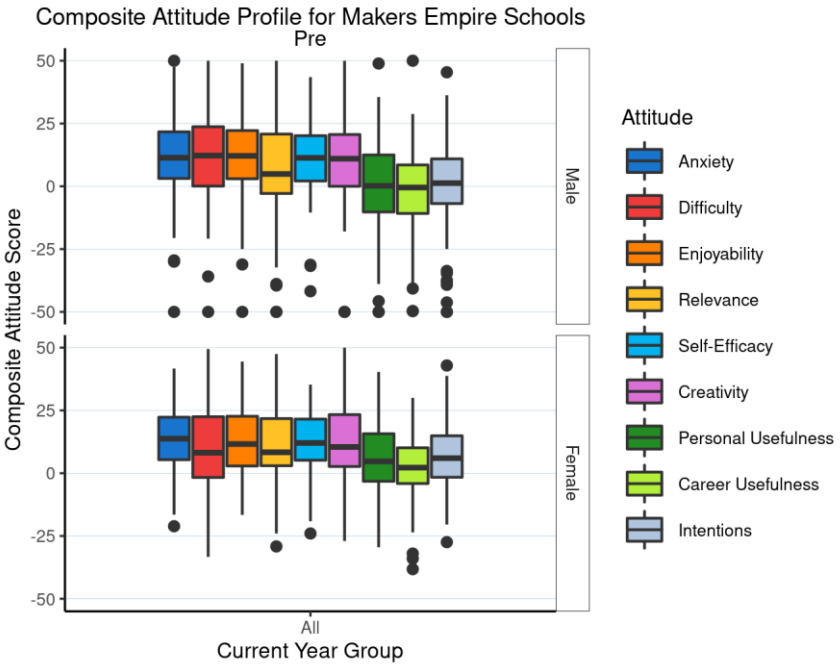

Figure 11: Students' Composite Attitude Profiles at the outset of the study.

Considering the subject of Digital and Design Technology (Figure 12) there are some small but interesting changes in student attitudes over the duration of the Makers Empire program. Prior to the program, students' average attitude ratings towards Digital and Design Technology were 5.3 points lower than all their subjects combined. Following the program, this average attitude rating had risen slightly to 3.4 points lower than their average composite rating. While no individual change was statistically significant at the 95% confidence interval, two measures were significant at the 90% level: Anxiety improved by 4.2 points over the course, $t(294) = 1.85$, $p = .066$; and Creativity improved by 3.7 points, $t(293) = 1.71$, $p = .088$. There was only one significant change in attitudes when the students were grouped by gender. Female students reported a 5.5 point improvement in their Self-Efficacy ($M_{post} = -0.6$, $SD = 13.8$) compared to their composite Self-Efficacy score and this was significant at the 95% confidence level, $t(139) = 2.30$, $p = .023$.

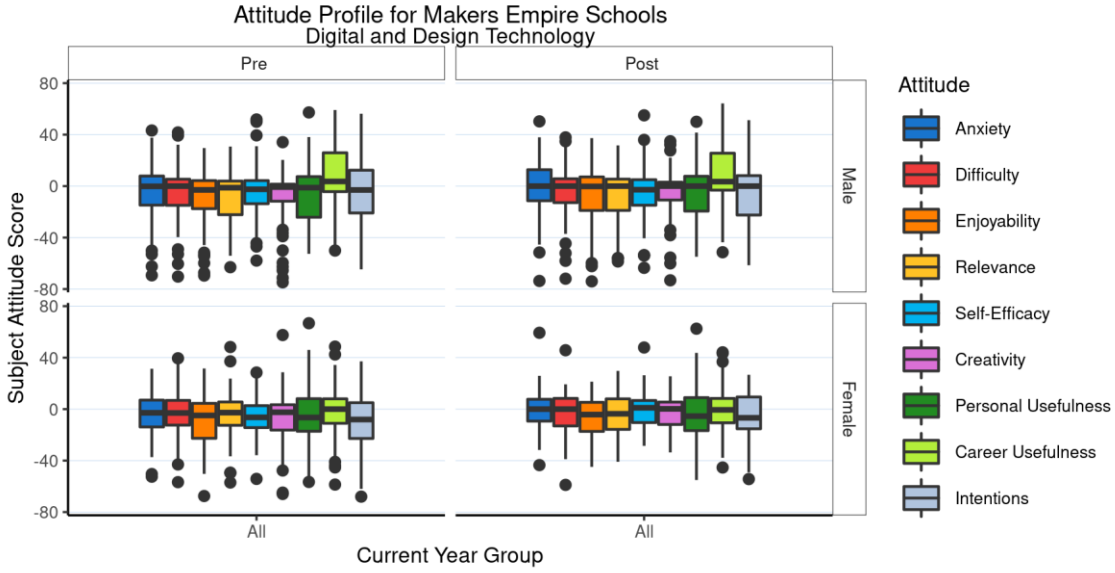

Figure 12: Student subject attitude profiles for Digital and Design Technology

It might also be expected that a program such as Makers Empire would impact student attitudes about mathematics (Figure 13). However, when considering the student cohort as a whole, no statistically significant differences were found between any attitudes pre and post, between student genders or between student year groups. It is likely that any impact of the Makers Empire program on students' attitudes towards Mathematics are masked by their other day-to-day experiences of this subject.

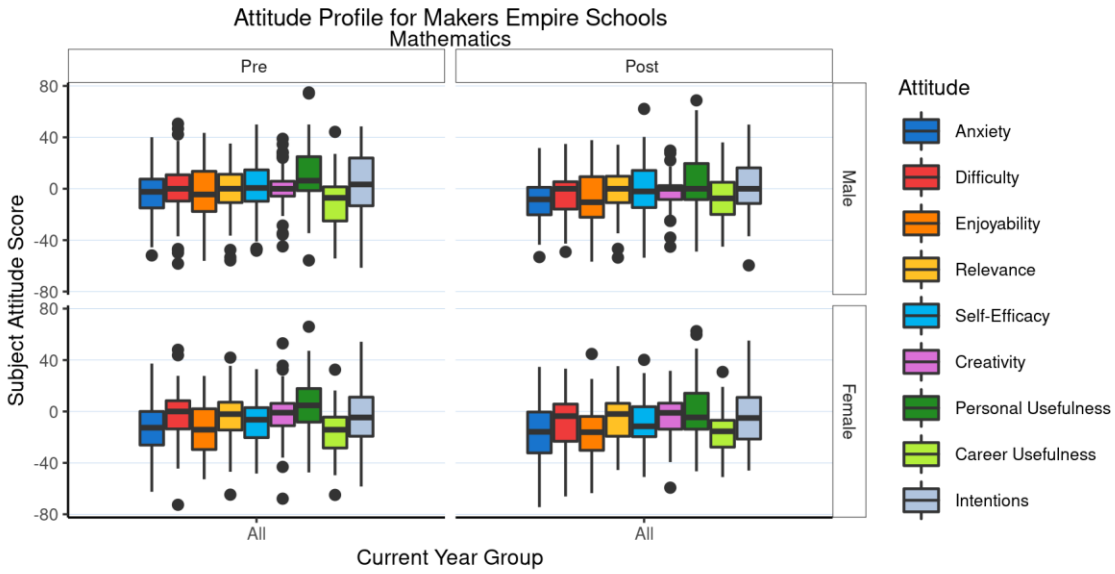

Figure 13: Student subject attitude profiles for Mathematics

Interrelations between SRI and SAS data

Four different student trajectories were highlighted in Figure 10 and 166 students (Table 3) also contributed SAS data alongside these SRI scores. To determine any differences between the students on each trajectory, pairwise two-sided t-tests were conducted. These compared average attitudes of each trajectory cohort towards Mathematics, Digital and Design Technologies and School in general.

While there are some small differences in the attitudes of students on each trajectory, they are not statistically significant. However, Trajectory A students showed a statistically significant change in attitudinal profile at the 90% confidence level that was not seen in any of the other groups. Between the start of the Makers Empire program and its conclusion, students on trajectory A showed a decrease in subject anxiety from 7.71 points to 0.21 points, t(88) = 1.852, p = 0.067, and an increase in Enjoyability from -12.48 points to -4.97 points, t(91) = 1.684, p = 0.095, for Digital and Design Technologies when compared to all their other subjects studied (Figure 14).

SRI Trajectory	Females	Males	Total
A	29	31	60
B	32	26	58
C	18	11	29
D	4	21	25

Table 3: Distribution of male and female students to SRI trajectories for students who completed both the SAS and SRI instruments

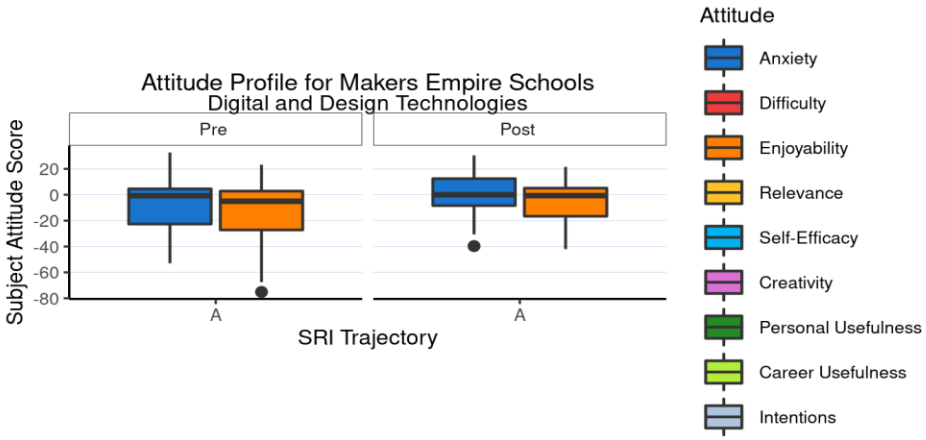

Figure 14: Attitude Profile for Digital and Design Technologies for students on SRI Trajectory A showing statistically significant changes only

DISCUSSION AND CONCLUSIONS

Students who undertook this Makers Empire program showed improved spatial reasoning abilities in all three subskill areas tested. Mental Rotation showed the largest changes, while Spatial Visualisation showed the smallest. These patterns might readily be explained by considering the skills and learning processes associated with using a computer aided design package like Makers Empire.

The students in this study generally had good attitudes towards school and low levels of subject anxiety at the outset of the program. While there were some very small gender differences in attitudes between students going into the program, these were not generally statistically significant. Over the duration of the program the data show that some students' attitudes—subject anxiety and enjoyability—towards Digital and Design Technologies did improve slightly.

"Female students showed a significant improvement in their self-efficacy towards Digital and Design Technologies."

Looking at the gender effects further, the data show that female students showed greater growth in SRI scores compared to their male peers. As female students tended to have lower SRI scores prior to the programme, this finding suggests that the Makers Empire program may be working to close the gap between males and females in terms of SRI skills. This finding could also be interpreted in terms of female students' ability to engage with the Makers Empire program. Further research may clarify the nature of the real underlying relationship present here.

The data also show that there are four distinct types of student trajectories when it comes to SRI scores. Students on all trajectories except the lowest show steady growth over the duration of the makers empire programme. These students—i.e., those students whose initial spatial reasoning skills were well below their peers— showed very little growth over the duration of the programme in terms of SRI skills.

"The Makers Empire program may have the potential to reduce anxiety and increase the enjoyability of digital and design education for students with weaker spatial reasoning skills."

While there are many potential explanations for this observation, the finding is nevertheless interesting in that it might suggest that a baseline level of SRI skills is needed to enable students to get the most from the Makers Empire program. There may be an opportunity here to develop additional challenges within the program to specifically target this type of student.

On the other hand, those students with an SRI score slightly below average at the beginning of the programme showed the most marked increase in SRI score. This group, who showed the greatest growth in SRI score, also reported increased enjoyability and reduced anxiety in Digital and Design Technology.

While not significant at the usual 95% level, this finding indicates that the Makers Empire may a useful platform to encourage students who might otherwise choose not to engage. As anxiety and lack of enjoyment are known to be blockers to student engagement in STEM, this finding is worthy of further investigation and research.

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