Greater Student Engagement in the Mathematics Classroom Through the use of Generative Activities Using the Ti-84 plus Graphing Calculator.

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Abstract

In Singapore, we recognise the need for greater engagement of students in the classroom to enhance the adoption of 21st century competencies. Schools are moving away from the drill-and-practice approach. An engaged learner in the 21st century is a student who is self-directed and able to define and articulate his learning goals and achievements. Lessons using graphing calculators coupled with the TI Navigator™ system were used to develop a group of secondary one (grade 7) students' conceptual understanding in algebra using networked generative activities and function-based algebra as well as to improve their engagement during mathematics lessons. This study adopted a quasi-experimental design with a project group from the school and a regular group from another Singapore school. The instrument for measuring conceptual understanding was a test consisting of a combination of MCQ and open ended questions. The PETALS Engagement Indicator (PEI) was used to measure students' engagement. Focus group discussions were conducted with students and teachers to gain feedback on the programme. Comparison using gain analysis on a 20-item test showed a small effect size on conceptual understanding and a moderate to large effect size for engagement - both in favour of the project group.

Key words: Engagement, conceptual understanding.

1.   INTRODUCTION

Singapore is a small island with an area of 640 square kilometres, a resident population of about 3.77 million (Department of Statistics, 2010) and no natural resources. The government therefore views the Singapore people as its only resource and invests heavily in their education (Ministry of Education, 2010a). It has put in place a meritocratic system of education which offers opportunities for every student to maximize his educational achievements. Students spend 6 years in the primary school system (P1 to P6), entering P1 at the age of about 6 years. There is a national examination – the Primary School Leaving Examination (PSLE) – at the end of P6 which determines the opportunities available for the student at the secondary level.

The typical path of a student who passes the PSLE is to enter the 4 year General Certificate of Education (GCE) 'O' level course offered jointly by the Ministry of Education, Singapore (MOE) and the University of Cambridge International Examinations. Students with weaker PSLE results enter a similar course at secondary level but typically finish it after 4 or 5 years. These students have the opportunity to graduate with a GCE 'N(A)' level certificate after 4 years or a GCE 'O' level certificate after one additional year. A third stream of students offers an alternative, slightly more coursework-biased course, which culminates in the GCE 'N(T)' level certificate. All three courses are offered in a typical neighbourhood secondary school like ours.

Since examinations determine which opportunities are available at the next level of study, the students' drive for a successful education is very strong in Singapore and this has both positive and negative effects on their learning styles.

In recent years, Singapore has featured well in international tests such as Trends in International Mathematics and Science Study (TIMSS) and Programme for International Student Assessment (PISA), with mathematics being one area in which the country is strong. In the four TIMSS surveys (TIMSS, 2010) of Grade 8 students in mathematics to date, Singapore has achieved top position in the first three surveys and came in third in the 2007 survey behind Chinese Taipei and Republic of Korea. In the 2009 PISA survey (OECD, 2009), Singapore came in second in mathematics to Shanghai-China. However, the students' strong showing in mathematics masks, we believe, underlying areas of weakness in their conceptual constructs which we feel we can make efforts to correct at school level.

Bukit Panjang Government High School (BPGHS) is an autonomous, neighbourhood secondary school in the western part of Singapore. The term "neighbourhood" determines that the school caters to all three streams of students – the four year GCE 'O' level stream, the N(A) stream and the N(T) stream. Separate curricula are required for each stream although there is considerable overlapping of topics. According to a 2009 press release from MOE (Ministry of Education Singapore, 2009), "autonomous schools" are schools which meet "the criteria that comprise the following broad areas:

- A well-rounded education programme and a good system in place to achieve the Desired Outcomes of Education;
- Consistently attained and shows ability to sustain good achievements in academic and co-curricular areas;
- Is well regarded and enjoys strong parental and community support and public recognition.

Autonomous Schools were established in 1994 to provide pupils with quality education through being given greater autonomy in school management. Autonomous Schools present parents with more options in the choice of quality schools for their children.

Autonomous Schools are given additional funding and flexibility to develop a holistic education that stretches each pupil to his fullest potential. Pupils from Autonomous Schools thus benefit from innovative curricula as well as a varied range of enrichment programmes. Autonomous Schools also have the flexibility of directly admitting pupils with niche-related talents into Secondary One under the Direct School Admission process. This is subject to a cap of 10% of the school's Secondary One cohort."

BPGHS was awarded autonomous status with the first batch of schools in 1994 and has maintained this status ever since. It is one of the few schools in Singapore to have been awarded the Singapore Innovation Class "*in recognition of commendable performance in innovation excellence*" by SPRING Singapore, the national standards and accreditation body. The move towards innovation was part of the school's response to MOE's development and promotion of 21st century competencies (Ministry of Education Singapore, 2010b) deemed important to the future development of the country.

Our school has been achieving consistently good results in both Elementary Mathematics and Additional Mathematics in the GCE 'O' level examinations taken at the end of grade 10,

scoring a mean subject grade of less than 2 in both Elementary and Additional Mathematics for the last 5 years. (Grades run from A1 which scores 1 point to F9 which scores 9 points, with A1 being the top grade.) While this is commendable, it has been noticed by teachers in the department that students' learning is principally based on memorizing solutions to problems coupled with much drill and practice. Time is spent in preparing for the national examinations by solving examination papers from other schools. Mid-year and preliminary exam papers from other schools are much sought after as sources of questions for students to practise and schools have even set up a Google account through which they share mathematics examination papers more readily.

The lack of conceptual understanding in our students was seen by one of the authors (Peacock) as a barrier to improving the learning of mathematics and the underlying concepts. A series of fortuitous events led to the development of a lesson package in secondary one (grade7). One of the school's mathematics teachers was sent on a short learning journey to Stanford Research Institute in California, USA. One of the researchers he met there, Dr Sarah Davis, subsequently joined Singapore's National Institute of Education. Dr Davis (Davis, 2007) and the school began a pilot project on networked Generative Activities for Singapore Schools, called GenSing for short. The lessons for secondary one were developed using function-based algebra and networked generative activities.

1.1   Function-based algebra (FBA)

Stroup (2005-2006) in his introduction explains FBA as "*more than just multiple representations and modeling. Much of traditional algebra as taught in schools centers on three core ideas: equivalence, equals (as one kind of comparison of functions), and key aspects of linear functions. Function based algebra can help with all three of these.*"

He goes on to explain how graphing calculators together with generative activities and classroom network technology can be used to deliver lessons which better develop understanding of conceptual constructs in elementary algebra. He (Stroup, Carmona & Davis, 2005) gives an example on page 3 of the way in which this can be done.

In BPGHS, the attraction of using FBA stemmed from the belief, gleaned from teachers' observations and anecdotal accounts, that not all students now joining the school were coping well with the traditional approach to the teaching of algebra. The approach in Singapore tends to emphasize the learning of algebra first with graphs and their uses coming later. Most textbooks rely heavily on rules for algebra with the idea of graphs seemingly being seen as an obvious extension of the rules. This approach produces students who are competent in drawing graphs – they are able to learn procedures and follow them well – but who have little or no comprehension of what a graph is or what it represents. For example, students in secondary 4 (grade 10) would, in general, be able to state the roots of a quadratic equation from the graph of the corresponding function but would have difficulty in explaining why this was so. They would be hard pressed to identify that the roots are the solutions to a pair of simultaneous equations – the equation of the curve and the equation of the *x*-axis.

1.2   Networked Generative Activities

The notion of generative activities as used in the Singapore classroom was developed by Davis (Davis, 2009) during the running of the GenSing project in our school. The essence of generative activities is to allow students to experiment with mathematics – to play with

mathematics – and be as creative as they can. They are removed from the notion of just one right or wrong answer which is so often prevalent in the maths classroom. In addition, the students are expected to put their current knowledge of algebra to full use in exercising their creativity.

The activities are networked by virtue of the fact that each student has a graphing calculator which connects wirelessly to a computer running TI Navigator™. Students are able to send their responses via the handheld calculator and Navigator™ shows a collation of all student responses on one screen. In the case of points which obey a linear law (e.g. "Input a point (x,y) for which the y is twice the x"), the students immediately see a pattern of points all (or most) of which lie on a straight line. Students work in groups and those whose points do not follow the pattern are able to correct their input with advice from group members. The teacher is able to freeze the action at any point and prevent further inputs. This allows for class discussion of a particularly interesting input which is also a good learning point. The student who sent in the input need not be identified.

1.3   Engaged Learning

There is a growing interest in the construct of engagement as it is seen as the antidote to low achievement. In this paper, we have focused on three types of engagement, namely behavioral engagement which draws on the idea of participation (involvement in academic activities of the class), emotional or affective engagement which draws on the idea of appeal like positive and negative reactions to teachers and the lessons themselves, and cognitive engagement which draws on the idea of investment. This includes being thoughtful, willing to exert the necessary effort for comprehension of complex ideas and mastery of difficult skills.

The vision of an engaged learner in the 21st century is of a student who is self regulated and able to define and evaluate his learning goals and achievement. These learners find joy in learning and are energized in learning collaboratively. This creates the foundation for a lifelong passion for learning/solving problems and students are eventually able to transfer their knowledge to solve problems creatively (Jones, Valdez, Nowakowski & Rasmussen, 1994).

2.   RESEARCH STUDY

A research study was carried out by one of the authors (Toh-Khor).This study was an attempt to verify that the use of ICT, specifically graphing calculators and motion detectors, through a series of GenSing activities does indeed increase the conceptual understanding of basic algebra. Answers were sought for the two research questions below.

1. Do students who use ICT achieve higher scores in tests of conceptual understanding in Basic Algebra (defined as consisting of 1. combining like terms, 2. identifying unlike terms and 3. distributive and associative properties of numbers) than those who do not use ICT?

2. Do students who use ICT to learn Basic Algebra have a higher level of engagement than those who do not?

2.1   Method

For this study, the project group (N=38) consisted of 14 male and 24 female secondary one Normal Academic (N(A)) students from BPGHS while the regular group (N=32) consisted of 17 male and 15 female students from a tail-end Express class in another Singapore school.

The N(A) students were using a mathematics textbook designed for the Express stream. This study adopted a quasi-experimental design where both groups came from intact classes. The profile of the two groups of students is summarized in Table 1.

Table 1: Profile of the 2 groups of students.

Participants	Total Number	Gender		PSLE Mathematics Grade			
		Male	Female	A	B	C	D
Project Sec 1A	38	14	24	8	15	14	1
Regular Sec 1D	32	17	15	14	16	2	0

2.2   Procedure

All the teachers involved in the programme had previously attended a series of professional training sessions led by Dr Sarah Davis from The Learning Lab, National Institute of Education, Singapore. There were two parts to the training - discussions on the creation of some of the activities and hands-on simulation sessions among the teachers on each of the activities prior to the actual implementation. These professional sharing sessions were conducted during the common professional development periods in curriculum time and, sometimes, in the afternoons outside curriculum time. Prior to the intervention, both the project and regular groups of students sat for a pre-test to determine if the two groups were equivalent. In addition, both students and teachers responded to the pre- intervention Petals^{TM} Engagement Indicator (PEI) (perception) survey. A one hour intervention was carried out on alternate weeks for the project class comprising 5 lessons over a 10-week period.

The classroom network used was the TI Navigator^{TM} system created by Texas Instruments Inc. This system consists of a teacher-controlled computer running TI Navigator^{TM} software, an access point, ten wireless hubs and forty TI 84 Plus^{TM} graphing calculators, one for each student. Each hub connects to four graphing calculators and transmits data wirelessly to and from the teacher's computer.

In class, the concept of function was introduced during the first intervention lesson, after which students were required to create a point each on the co-ordinate plane obeying a particular rule which was described in words in the worksheet. Students were to interpret the meaning mathematically and create a point with coordinates which agreed with the rule. If the majority of students answered correctly, a pattern would emerge on the screen (a straight line of points). Students were challenged to look for and verbally describe a pattern in the points obtained and create a function (in the form of a relationship between *x* and *y*). They were then to type their function into their calculator and send it back to Navigator^{TM} which displayed the points and the graphs of the functions on the same screen. Students were able to view both the points and functions created by their peers and teachers could facilitate a discussion on the images produced on the screen.

Discussions could focus on why there were a few "rogue" points which did not follow the pattern observed on the screen. Students who had keyed in erroneous points were not identified but the coordinates of the points could be seen and corrected. Similarly, discussions about gradients could also be facilitated at this time.

In subsequent lessons, students were encouraged to create different expressions for the same function, determine rates (gradient), examine how change of speed affects the speed-

time graph, etc. For example, instead of having the students simplify $\frac{25x+7x}{8}$, they were challenged to come up with 3 expressions which were the same as 4*x*. They checked that they had identified equivalent expressions by graphing the functions and comparing their graphs. The graphing calculator was the student's private space and the projection on the teacher's computer was the group's space.

The idea of generative activities is well illustrated in the approach we used for distance-time graphs. Traditionally, students are either given a problem on distance-time, are guided through the process of deriving a graph to illustrate the problem and are then asked to make deductions from the graph they have produced. or they are simply given a graph and asked to make deductions about the motion described by the graph. Our students were given a worksheet containing a set of graphs, a graphing calculator and a motion detector connected to the graphing calculator. They were required to create the graphs shown in the worksheet by moving their bodies in front of the motion detectors. In other words, students generated the graphs by their own motions in front of the detectors. By varying distance, speed and direction, they were able to vary the graph produced by the calculator.

At the end of the project, students from both groups sat for the same post-test. All the teachers involved in the implementation and six students (2 each from the high, average and low ability in mathematics) were identified for a focus group discussion (FGD). Teachers and students from both groups then responded to the post-intervention PEI survey.

2.3 Measures

2.3.1 Achievement test: A test consisting of 20 items (a mixture of MCQ and open-ended questions) totaling 40 marks was used to measure the conceptual understanding of the students. More marks were allocated to questions requiring higher order thinking. One of the questions involved drawings of tiles obeying a particular pattern. Students were to compute the number of tiles used at each stage in the pattern, make a generalization on the pattern presented, describe in words the rule that he had used to figure out how many tiles were used at each stage and then write the rule as a function.

2.3.2 Survey Questionnaire: The PEI survey was used to assess students' engagement level during the mathematics lessons using this new pedagogy. This survey contained 68 questions pertaining to Pedagogy, Experiences of Learning, Tone of Environment, Assessment and Learning Content. A detailed exposition on the development and validity of the PEI can be found in Dr. Soh Kay Cheng's chapter (Soh, 2007) in The PETALS[TM] Primer. Students responded to the statements on an 11- point Likert scale ranging from 0-Strongly Disagree to 10- Strongly Agree. This questionnaire included a descriptive component where students described a lesson in mathematics using ICT to a friend.
The questionnaire was made available to students online and the school organized sessions - within a window period specified by MOE - for the students to use a computer lab. in school to answer the questionnaire. The sessions were held after the regular curricular lessons had ended for the day and before Co-Curricular Activities CCA) had begun. However, due to the extensive nature of the questionnaire, it was difficult to make arrangements

within the constraints of computer laboratory availability for all students in the sample to take the questionnaire. This caused a slight variation in the sample sizes.

2.3.3 Data Analysis: There were two parts to the analysis:
i) Analysis of results of the pre- and post-test to gauge if the conceptual understanding of basic algebra of students had improved
ii) Analysis of students' responses to the PEI survey in particular; the affective, behavioral and cognitive engagement components to gauge if there was an increase in engagement during the GenSing lessons.

3. RESULTS AND DISCUSSION

The regular group scored better than the project group by a difference of - 2.1 marks on the pre-test. As the Standardized Mean Difference (SMD) for the pretest was - 0.49, we concluded that the two groups of students were not equivalent at the beginning of the intervention.
The post-test mean showed a difference of 0.5 marks with a small positive SMD of 0.10. As the comparison of the post-test did not take into account their initial difference of small size SMD of -0.49, gain analysis was used on the post-test scores to determine the effect of this new pedagogy.
When this was filtered in, the project group did better in the post-test by a margin of 3.5 marks with the corresponding SMD of 0.45 indicating a small effect of this new pedagogy in favour of the project class.

Table 2: Comparison of Project and Regular Group on Conceptual Understanding**.**

	Project Group (N = 38)		Regular Group (N = 32)		Effect Size
Mean	Mean	SD	Mean	SD	SMD
Pretest (40m)	12.9	4.29	15.0	4.17	- 0.49
Post test (40m)	19.9	4.19	19.4	5.18	0.10
Gain	7.0	4.37	4.5	5.69	0.45

The two classes had full attendance for the pretest and post test, which was organized as a class test in the students' own schools. For the second research question, there were some absentees on the dates of the online testing which resulted in sample sizes which were slightly different from those of the pre- and post-tests. On whether there was a higher level of engagement, the two classes were not equivalent on the cognitive component of the engagement scale as the SMD for the pre-PEI survey was 0.27 (Table 3). Gain analysis was used on the post-PEI survey to measure the effect of the new pedagogy on students' cognitive engagement. Throughout the generative activities lessons, students in the project class were observed to be thinking aloud, deliberating on their solutions, checking with peers in the group and reaffirming their thinking through visual (graphical) representation when they sent in their responses through the Navigator[TM] system. Responses in the post-test showed a higher proportion of students in the project class were able to generalize and translate concrete patterns into symbolic/algebraic representations compared to the

regular class. To exhibit conceptual understanding, students must be able to switch from one form of representation to another, make linkages between these multiple representations and as one student from the project group blogged in the PEI survey: *"We have to use the GC (graphing calculator) and come up with some equation and plot the graph,…During the GenSing lessons, we really need to concentrate and think, if not, it would be difficult to understand the concept that was given. When we want to check the answer, we look at the graphs."* The results of the post PEI survey yield an SMD of 0.74, showing a moderate impact on cognitive engagement as summarized in Table 3 below.

Table 3: Comparison of Project and Regular Group on Cognitive Engagement.

	Project Group (N = 37)		Regular Group (N = 30)		Effect Size
Mean	Mean	SD	Mean	SD	SMD
Pre-Survey GC (100m)	62.1	20.27	57.0	18.73	0.27
Post-Survey GC (100m)	71.4	14.95	54.1	16.85	1.03
Gain	9.3	25.00	-2.9	16.53	0.74

The pre-PEI survey showed that both classes were equivalent on the affective and behavioral components of the engagement scale with each having an SMD of 0.07 and 0.01 respectively. On affective engagement, the collaborative effort described above and positive affirmation from both their teacher and their classmates encouraged the students to explore further in order to verify their thinking and/or their solutions. Once students experienced success in solving a problem, they gained confidence and it was observed that the "feel good" factor led to them working on more problems, resulting in higher engagement during the lessons. One student stated during the FGD *"Our teacher gives us feedback so that we can improve on our work, hope we could have more GenSing lessons in the future"* Another student mentioned in the blog: *"I started to like Maths, the motion detector detects your movement and plots the graphs of the movement onto the calculator; I look forward to every GenSing lesson and hope to have them next year."*

All the observations were further reinforced by the results obtained in the post PEI survey which yielded an SMD of 0.8 (Table 4) showing a large effect on affective engagement. One of the advantages of using the Navigator^{TM} system is that students could view the data sent in by all students synchronously and yet remain anonymous. We believe that this is especially crucial in mathematics to engage the quiet or weaker students who normally would not respond in the normal traditional form of frontal teaching.

Table 4: Comparison of Project and Regular Group on Affective Engagement.

	Project Group (N = 37)		Regular Group (N = 30)		Effect Size
Mean	Mean	SD	Mean	SD	SMD

Pre-Survey GA (100m)	60.4	22.29	58.9	20.63	0.07
Post-Survey GA (100m)	68.1	20.43	53.4	18.45	0.80

During the focus group discussion with teachers after the intervention, the following points pertaining to behavioral engagement were noted. Students set up the graphing calculators & Navigator[TM] system promptly, an indication of their eagerness to start the GenSing lessons. There was a higher level of interest in the mathematics classroom when GenSing activities were scheduled and more discussions were observed during these lessons. In addition, students working in groups tended to ask more questions, seeking clarification among themselves and also from the teacher. Teachers observed that during these activities, there were more opportunities for students to explain their solutions and for the teacher to facilitate discussion, provide scaffolding and help them in articulating their thinking. All of this appeared to have a positive impact as it was observed that students tended to hand in their assignments more promptly. The observation was further supported by the Behavioral Engagement Indicator yielding an SMD of 0.97 which is considered to indicate a large impact. Other interesting feedback during the focus group discussion with students on ICT lessons included "*having opportunities for exploration, learning about teamwork, learning from friends and excited about how algebra can relate to graphs.*" The findings are summarized in Table 5.

Table 5: Comparison of Project and Regular Group on Behavioral Engagement**.**

	Project Group (N = 37)		Regular Group (N = 30)		Effect Size
Mean	Mean	SD	Mean	SD	SMD
Pre-Survey GB (100m)	62.2	15.08	62.0	19.19	0.01
Post-Survey GB (100m)	71.5	16.38	55.0	16.94	0.97

It can be seen that there was some benefit using GenSing to engage students in learning compared to the traditional form of teaching. The higher engagement level should ultimately translate into higher achievement scores, and feedback from teachers on the semestral exam immediately following the intervention was that students were able to describe correctly how an object moved corresponding to the graphs given in the paper.

4.   CONCLUSION

The results obtained for this research are quite promising. The department will fine-tune the current set of activities and identify more topics where this pedagogy can be used. Getting students to articulate their thinking is consistent with the school's strategy of trying to

create students who are confident communicators. The excitement generated by the graphing calculators and the different setting in which they are used leads students to be more relaxed and vocal. They are more willing to discuss options with their peers as well as ask for clarifications from their teachers.

Once greater familiarity with the system on the part of both teachers and students is consistently achieved, more topics can be redesigned to make use of the graphing calculators and the TI Navigator^{TM} system. While teachers find the engagement of students refreshing and encouraging, the challenge presented to them is in the mastery of the software as well as their ability to handle all the components of the system while delivering a coherent lesson to a class of 40 students. It is a skill which has to be developed over time.

Suitable training for the teachers and greater use of the graphing calculators within the lower secondary curriculum will, we believe, lead to more encouraging results. The intervention will be spread over a longer period with more frequent use of the Navigator^{TM} system during the mathematics lessons, resulting in a more varied pedagogical approach and providing more opportunities for student engagement within the mathematics classroom.

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