USING PROGRAMMING WITH RURAL CHILDREN FOR LEARNING TO THINK MATHEMATICALLY

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Is it possible to use computer labs in a rural setting that encourages reasoning, visualization, abstraction in children (as envisioned in NCF 2005) while at the same time addressing curricular needs? This paper addresses the question through the use of programming in two rural schools including integration of curricular areas for fractions, cube roots, algebra, compound interest, data handling, geometry, etc. We explore three styles of instruction - projects for children to demonstrate their understanding, challenges to visualize abstract concepts, and games created by children themselves for mastery.

CONTEXT

We are presenting the work in two outreach schools of Auroville – Isai Ambalam School and Udavi School- that cater to the villages of Annainagar, Edyanchavadi, Irumbai, Pooturai, Pattannur, etc. We used **existing** computer facilities of the school, working with children on Mathematics through programming.

These are rural schools and have demographics similar to government and NGO run schools throughout the country. The schools believe in the holistic development of the child and school managements are progressive and encourage experimentation and research. From middle school onward much of the time is spent on academic subjects, in line with the expectation of parents. Both the schools have computer facilities. In this sense too they are typical, as over 75% of the secondary and higher secondary schools have computer facilities (DISE, 2014).

Aura Auro Design is a team of four engineers who volunteer 3 hours a day at the schools. We work with around 50 children from 6-8 grades along with their teachers. Classes range from 8 to 16 children. We are presenting the use of programming in this paper, however, we complement programming with puzzles, and strategy games, building physical models and TLM to create an environment of joyful mental exploration in the schools (Ranganathan, 2014).

Philosophies in Learning

Constructivist Education Theory (Bruner, 1960) indicates that knowledge is not delivered into the learner (whether child or adult) but recreated by the learner on his or her own. Children actively construct their knowledge by connecting new knowledge to what they already know. Constructivist education encourages discovery learning and learning by doing. It encourages activities that challenge a child's worldview since conceptual change and deeper conceptual learning come from experiential and interactive activities. Bruner further suggests “spiral learning”, claiming that any subject could be introduced to any child at any age if it is in some form that is honest.

In India, Sri Aurobindo (Aurobindo, 1910) indicates that nothing can be taught, but the teacher can support and encourage a child in the process of learning, thus guiding them towards perfection. More recently, Mukunda (2009) describes the three aspects of learning that are relevant to schools - conceptual knowledge, procedural knowledge and higher order reasoning. Conceptual knowledge (and change), she states, greatly benefit from constructivist approaches. In this paper we look at all three aspects of learning.

The Constructionism theory (Papert & Hare, 1991), adds to the constructivist theory the belief that children construct their own knowledge best by creating something outside their minds that is often sharable. In this research project, we explore creation in the virtual media through computer programming.

The National Curricular Framework 2005 (Pal et al., 2005) states that the 'useful' capabilities relating to numeracy, number operations, measurements, decimals and percentages are only a narrow goal of Mathematics education. Most middle schools across the country focus on these narrow goals for better marks in examinations. Examinations presently test children primarily on procedural learning: drill and rote learning become the primary tools for education. The NCF 2005 points out that across the country children do not enjoy Mathematics and are poor at applying these concepts or handling complexity.

The higher purpose of Mathematics, it says, is Mathematization: the understanding and application of mathematics in different situations with a focus on abstraction, patient problem solving and logical thinking. Meeting this goal requires a fundamental change in the approach used in schools. It requires classrooms to move away from simplistic 'sums' to more complex problem solving and contexts. It requires a shift in conversations in the classroom from the 'right answer' to considering and discovering approaches to problem solving. Our team thinks of Mathematics **in its wholeness,** achieving higher goals while also meeting the narrow goals. We also provide alternative ways for children to demonstrate their mastery of a subject beyond examinations.

We believe that the teacher is not an instructor or taskmaster, but a helper and a guide (Aurobindo, 1910). We believe that as teachers we should be aware of the situations when we need to step in (technical difficulties – mouth down frustration) and when we need to step back (struggle necessary for learning – mouth up frustration) (Martinez & Stager, 2013).

Programming and Children Learning

Use of programming to teach children Mathematics (Papert, 1986) happened before personal computing had reached its peak. A programming language LOGO was created to help children communicate with the computer and instruct a robotic “turtle” that could move and draw on paper. The positive effects of programming on children's cognitive learning were also examined (Pea & Kurland, 1984). A variety of hardware was made accessible to children to program including cars and robots (Lego Mindstorms) and resulted in the Maker movement.

The Maker movement focuses on learning through inventing: making, tinkering and engineering (Martinez & Stager, 2013). **Making** taps into the innate nature of human beings to create and its active role in learning requires visualization of a 'product'. **Tinkering** is a mindset – a playful approach to solving problems through experience, experimentation and discovery. **Engineering** is the process of extracting the principles from experience and organizing it to bridge intuition to formal learning, enabling better understanding and prediction of results. We find all three aspects necessary in our research for a more meaningful way of utilizing computers in school.

Programming Language and Setup

Scratch 2 (Resnick et al., 2009) is an advanced visual programming language built beyond the capabilities of LOGO. It has a low floor (easy to learn: you can stitch code together), high ceiling (includes variables, functions and event driven simulation) and broad walls (allows for users with different interests from drawing, music, animation, and computation). The availability of such a program at no cost enabled us to use it with rural children who have limited English skills to take up programming.

We used the Scratch 2 off-line editor to enable work without the internet. We installed public domain OS Ubuntu 14.04. The OS and software(s) are available free of cost and offline and the setup can be replicated in any computer center rural or urban across the country. We also set up a local LAN to allow centralized storage of files. This allowed children to save and continue their work from any machine. The complexity of the children's programs significantly increased when they were assured that their work was saved and available.

Educational Computation and Children Programming in India

In urban India there is a significant movement for children to learn programming beyond school. Among younger children Scratch is a popular program. Computing availability in rural India is limited and when computer facilities exist, they are rarely used beyond an hour or two in a day in a school.

Progressive schools do introduce children to Scratch, sometimes as a creative medium for animation and to develop higher level thinking. In Udavi School Scratch was already used by children. With minimal guidance they had played and tinkered with example games.

USING PROGRAMMING WITH MATHEMATICAL CONCEPTS

We present these case studies of different aspects of children's learning through programming.

Cubes and Cube Roots

Pooja (8th grade) encounters cubes and cube roots; she often mistakes x^3 (x multiplied by itself three times) with $3x$ (x multiplied by three). For perfect cubes (e.g. **830**58<u>4</u>) one can guess their two-digit cube roots (e.g. **9**<u>4</u>) by estimating how big a number is (how many 1000s) and looking at its unit digit. I hoped this would help her get a sense of numbers. She was unable to follow the procedure and had difficulty with the sense of numbers. (She is not alone).

She starts to program to find the cube roots of numbers. Her initial goal is to print the first 10 cubes. Power is not an available expression and she needs to construct the expression for a *number* (variable). In time she creates *result=number×number×number*. She increments the *number* each time and puts it in a loop. To view the results, I ask her to add a delay of 1 second after each operation. I ask her to notice the numbers, but she doesn't find a pattern. She then changes the loop condition to keep running till the *result* becomes a large cube given in her book. Now, she is interested in where the program stops and intently looks at the results. She soon figures out when she is too far and needs to wait for the result and asks to reduce the time between calculations. I tell her she could change the program for fewer calculations, but retain the time after a calculation to see the result.

She decides to skip numbers in her program. I connect it to the original process and ask her to change in steps of 10 (10, 20, 30, etc) till the *result* is too large, go to the previous step and then go in steps of 1. She implements this as two loops: first loop in steps of 10 and second loop in steps of 1. It takes her time and she makes errors, but she understands what she is trying to do and debugs it with known cube numbers and their cube roots.

To use the program she generates a random two-digit number (feature available in Scratch) and uses its cube as the *target* (variable). This time when she looks at the steps of 10 she notices the last three digits are 000s. She then notices that the non-zero digits have the same pattern as cubes of single-digit numbers. When the second loop starts the numbers are much more complicated. I ask her to focus on the units place. Now, she notices a pattern e.g. 1 in the units gives 1 in the units of the cube ($\mathbf{2}\underline{1}^3$ = $\mathbf{9}26\underline{1}$). Similarly, 4 gives 4, 5 gives 5, 6 gives
6, 9 gives 9. The others were flips 3 with 7 ($\mathbf{4}\underline{3}^3$ = $\mathbf{79}50\underline{7}$ and $\mathbf{5}\underline{7}^3$=$\mathbf{185}19\underline{3}$) and 2 with 8.

She starts working this out systematically as the computer does and now she gets it. In time she skips the 'unnecessary' steps and gets straight to the cube of the 10s before and (to check the 10s after) and then writes the number including the units. She makes the program a game that accepts inputs to check her answer. The program still works through all the steps for her to cross check her thinking and then announces if the result is accurate. In the next class she works out 50 cube roots in an hour in her notebook and checks with the computer. She gets one wrong and understands why that one confused her.

She now revisits squares wanting to do something similar there. Though the numbers are smaller the process is more involved as it has the mapping in the units place and is not one-to- one (e.g. units place 4 and 6 result in a square with units place 6) and you need to estimate which square it is closer to. However, she masters it by following a similar process.

In this example we see that it is possible to learn a higher order skill – sense of numbers, logically thinking with learning a procedural skill and developing an understanding of the concept. We also notice that in the process of creation the learning becomes her own.

Multiplication and Corresponding Division Stories

Much of science that children encounter in school is one quantity (distance) as a product of the two others (speed and time). Other examples are density, mass, volume; mass, force, acceleration; changing units. The simplest form of these boil down to:

Multiplication story: 1 box has 6 apples, how many apples are there in 4 boxes.

Division story 1: There are 24 apples in 4 boxes, how many apples are there in one box.
Division story 2: There are 6 apples in 1 box, how many such boxes are needed for 24 apples.

Rahul (6th grade) seemed to get the concept, but was unable to retain it. He started to create a program to animate his story. Scratch provides a stage and you need to bring in characters that do their part. He needed to think of a concrete example and stay with the example while he programmed the appropriate apples and boxes to appear and disappear based on his story. He needed to synchronize the timing of his voice and the corresponding display. The rigor of staying with a problem helped him to retain this concrete story. Knowing one concrete example well helped him abstract other stories. The process of personalization of learning through the process is so strong that at the end of the year when we displayed the work of children, not just Rahul, but every child could recognize their work by just the initial stage even before we started playing their demonstrations.

Circles

We planned to use the process of personalizing the projects for adding fractions as well. In visualizing fractions the children decided to use a circle to represent the whole (as it's obvious

when something is missing). We added a constraint: children would need to instruct (program) the computer to draw rather than draw themselves by hand.

Scratch has bare bones pen commands allowing you to draw from point-to-point (lines with coordinates) or lines of arbitrary length at arbitrary angles from a point. How then do you get a circle (more accurately a good approximation of a circle) with lines?

With *making* of the fractions project in mind, the children started to *tinker* with various shapes with lines that would resemble a circle. This led to interesting conversations about what fundamentally a circle is, something that is constantly changing its angle. They then broke the full angle (360) into angle chunks, moving a constant distance and rotating by that angle chunk (*engineering*). Depending on the size of the chunk they got various regular polygons. Starting from equilateral triangles to squares to pentagons and so on finally settling at a shape with large enough sides to look like a circle. Eventually, a simple program *repeat 360 {move 1 step; rotate 1 degree}* gave them a very good approximation of a circle.

Fractions

Given that we had spent quite some time on this wonderful deviation we decided to experiment with a higher level thought process for playing with functions and created a base function for drawing a fraction with various inputs. The idea of controlling where the fraction should be drawn, and how big it should be was a significant exercise in their understanding of coordinate geometry. The last screen of such an animation by Ahalya (7th Grade is shown below).

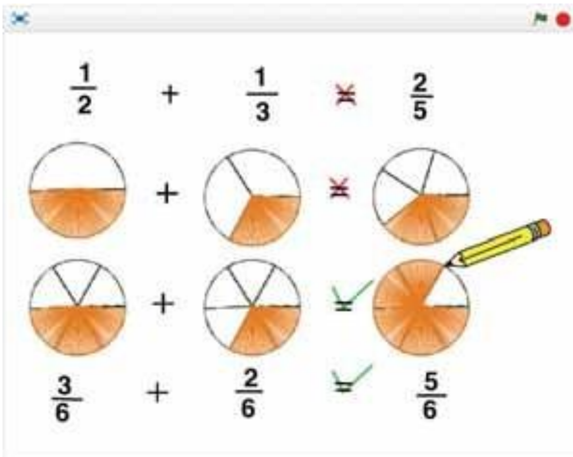

Figure 1: Final image of one animation project on fraction additions

Children who participated in that session were required to think in a different way about circles and were asked to examine fractions in detail. A few months after making their animations the children were tested on adding fractions. All of them knew that you couldn't just add the numerators and denominators, most were able to create equivalent fractions to add fractions, and, on being prompted half were also able to resort to LCM to add fractions which is the expected procedure.

Percentages, Algebra, Compound Interest

The conceptual understanding of abstract concepts were better understood by children when they were asked to demonstrate their understanding visually. For percentages they created programs to make pie charts of the time spent on activities in a day. For this they took the hours and framed fractions of the day, scaled angles with different colors of the pie and also represented percentages. This helped them link multiple independently dealt with concepts at the same time. The process of debugging (fixing errors) helped them face the assumptions and misconceptions they had e.g. Jaya had assumed that now that she was working with percentages fractions needed to be scaled by 100 for everything including angles. Only part of her circle appears densely colored. She debugs her program and realizes that even though they are dealing with percentages it does not scale angles automatically from 360 degrees. This helped Jaya realize that what she knew before had not suddenly become irrelevant now.

Data Handling

The fundamental art in having to explain something to a computer is that children need to be clear about the procedure and break it down into simple steps they can code. Equally importantly, they need to create test cases that they are absolutely confident of. The meta- cognition of average children in middle school is low and being able to say they are absolutely sure of something, especially a new concept, gets them to stretch beyond their comfort zone. They start trying to understand the concept to come up with a simple test case

e.g. one group of children were trying to get an average in their book exactly right, in another group a child started a discussion on what would happen if all the data was the same since this was easy to generate on the computer, indeed this resulted in a much more trivial test case, but more involved understanding of the concept. As before, plotting the results helped them estimate averages even before calculating them. Further, Scratch's ability to create large random data helped them notice the law of large numbers by themselves i.e. average of randomly distributed data between two numbers tends to be the average of the two numbers.

Observations

As children explain a procedure step-by-step through programming it helps clarify these procedures in their minds. Further, it fundamentally changes their relationship with computers. In the year-end surveys one of the children remarked that only now she understood how much effort and intelligence it goes into making the computer *look* smart. Other than the appreciation of what it takes to do something in real life, the import was that she no longer considered the computer smart *in itself*. Computer usage in schools is generally an extension of an authority figure which is always correct e.g. softwares that explain something to children or test them (openly or through 'games'). In these cases, the computer is all knowing and always right and children have nothing to offer to it but 'right' answers. It provides no scope for invention, questioning or possibility of higher order learning.

MAKING, TINKERING, ENGINEERING

Conversations which lead to learning in deeper mathematics can come up in many making situations. As part of the study on the moon the children in 7th grade decided to make a time- scaled animation of the earth spinning on its axis, going around the sun with the moon rotating around the earth. They also decided that they wanted earth to travel in an ellipse rather than a circle. This started an exploration of how to get an ellipse rather than a circle.

One solution took them through attempting to extract this information by solving the equation that Geogebra gave. The idea that a two dimensional expression e.g. $1.37x^2+2.25y^2-61798.1$ that they did not know how to process could be solved by the computer by selecting a value of y and sweeping x till the expression became zero was fascinating for them. Since they were drawing pixels they only needed the integer part of the solutions, but a curve does not only have integer solutions. They needed to use the fact that expressions change sign when it steps over the solution (expression changes sign as it crosses zero). They developed a healthy respect for integer multiplication when they realized that this could use the product of two successive results to locate a solution (*engineering*).

The children *tinkered* around with the limits of using these sweeps and realized that in closed curves there are no solutions beyond a *y* value point for any value of *x*. The earth was now rotating around the Sun. For a sum that is generally simple getting an answer is enough, however, in making you can gauge the quality of work and there is always room for progress.

The children noticed that the earth seemed to be speeding up the upper extremes (y was being stepped linearly and the slope was close to zero). They further tinkered and made multiple ranges putting points closer together as they came to the extreme to compensate for change of slope.

Another group of children simply tinkered around longer to come up with a different solution by visualizing the circle as getting stretched in the center to create an ellipse. They divided the angles between a smaller and bigger circle to achieve the same result. The code went something like this *repeat 45 {move 1, rotate 1}, repeat 90 {move 2, rotate 1}, repeat 45 {move 1, rotate 1},* and so on for the other half of the ellipse.

DIFFICULTIES AND ASSESSMENTS

Most children we worked with had already been using the computer to play (educational) games, watch videos or work with Paint. Their initial excitement for using the computer had died out and there was resistance to intellectual work using the computer. What helped us was that children still enjoyed making and tinkering (as suggested by their surveys). The drift to engineering depends on the ability of the instructors to create a situation where children want to create a project and struggle to find a solution with tinkering and want more predictability in their work e.g. making a circle can be accomplished through tinkering, but making a set of specific circles needs understanding about perimeter and radius of circles.

Initially, the time projects took concerned us. We gave it time since the children were engaged and challenged. Teachers spend a lot of time repeating concepts that the children apparently learnt and have 'forgotten', when in fact, the children had not really learnt it (Brooks & Brooks, 1993). We found that children retained concepts they learnt over time.

The biggest difficulty is actually that we, as teachers, want to teach (and instruct) but that often steals the most important learning from the child. In time we learnt to notice when we were too keen to teach and learnt to step back to allow the children to struggle and learn on their own.

One group of girls had created a wind chime, calculated 22.5% lengths of the pipes, hacksawed the steel pipes, used a power drill to drill holes and complete their product. When we did surveys with the children at the end of the year we had expected this to be the top of their list of accomplishments. It was hence a surprise when Ahalya indicated that the fractions program (Fig. 1) was her finest work. I reminded her of the wind chime, she smiled and said that it was a great experience, but the fractions were her best work. It helped me realize that in this increasingly technological world children see the virtual world as something tangible and real.

CONCLUSIONS

Programming allows an important interaction between a child and a computer altering fundamentally the equation for being a user to being a programmer, from being a receiver to being a creator. Programming is significantly different from using passive media that converts the computer to a personalized television, or enables children to play games on the computer as users only. This fosters the assumption that the computer is always right and we/they are always playing catch-up. We must let children program the computer instead of attempting to program the children through computers (Papert, 1993).

Making projects (through programming) can be a way for children to demonstrate their learning and offer alternatives to examinations as the only form of assessment. This also offers an opportunity for self-evaluation and constant progress.

Programming a computer helps children learn conceptual ideas because they need to break it down into small bites for a computer to follow. It also helps them visualize abstract concepts. They can also create their own games to develop rigor.

Rural children are growing up with an increasing access to technology and programming can be meaningfully used with them to support their higher order learning and mathematical thinking while addressing curricular aspects in a more meaningful way. This paper is a case study intended to show that the 330,000 schools across the country that have computer resources could use this resource in a creative way to develop higher order reasoning skills through discovery and invention while addressing useful academic skills.

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Notes:

Learning Mathematics concepts through Projects and EBD(Education by Design) methodology

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ABSTRACT

Context

We are a team of engineers who run STEM (Science Technology Engineering Mathematics) land – that are rural STEM centres in two outreach schools of Auroville – Udavi School and Isai Ambalam School. Both schools aspire towards holistic development of the child and the managements are progressive.

The children attending come from villages surrounding Auroville.
Udavi School follows the state board syllabus and we work with ~56 children from 7th to 10th intensively for 6 hrs/week for all their Mathematics (Math) classes. Isai Ambalam School follows the central board syllabus and we work with
~71 children from 3rd to 8th grades intensively for 6 hrs/week during the Environmental Sciences (EVS) and Math classes. In demographics, the occupation of parents in both schools is in unorganized labor e.g. masons, painters, agricultural labor and schemes providing rural employment. The predominant community accessing Udavi School is MBC (Most Backward Caste) and that accessing Isai Ambalam School is SC (Scheduled Caste).

At STEM land children learn Mathematics, Electronics, 3D Printing,

Programming (in Scratch, Alice, Geogebra), Mindstorms (Robotics) and play strategic games that enhance logical thinking. The children take responsibility of their learning and plan their goals each week related to their curriculum and beyond it. This self-directed learning is based on Sri Aurobindo's first True principle of education (Aurobindo, 1910); "Nothing can be taught". They create projects that represent their mastery over concepts they learn and can share following constructionism (Papert, 1986). They and work individually, in pairs or peer groups and ask for support from facilitators when they need it. With younger children we work on real life projects that impact their surroundings.

In this paper, we are sharing our experience as practitioners, of how different children learned Mathematical concepts such as sets, algebra, measurements, ratios and percentanges at STEM land. We also look at how technology (both physical e.g. building/construction and virtual e.g. programming) was effective in aiding this process. We will take some case studies.

Case studies

Sets and Algebra: A few children from 10th grade in Udavi School had built a physical game with a chart representing Venn diagrams (where each Venn Circle represented a rule e.g. one for color and one for shape). There were tokens (e.g. red circle) representing characteristics that the player can place and check if it fits in a section of the Venn diagram. The goal is for the player to determine the original rules of the Venn Circles.

This game inspired Diva, a 9th grader the built this game in Scratch. Scratch is a visual programming language that allows children to build interactive games, animations that are used extensively at STEM land by children to create projects. It requires children to break down a problem into simple enough components so they can be understood by the computer through instructions. We have seen that this helps children learn concepts in a more concrete fashion (Ranganathan s, et al 2015) while improving problem solving, logical reasoning, etc.

In this case, Diva realized that in order for the computer to understand which region of the Venn Diagram was being accessed he needed to divide the Venn diagram (for 2 circles) into A-B (in A and not in B), B-A, A∩B (in A and B), and U-AUB (outside the two circles). Even though visually it looked like a single picture it was in fact composed of 4 different pictures (or sprites). This also helped him understand the different regions of the Venn diagram better. Creating these separate shaped areas allowed him to use sensing of a new object (token) to determine if it belonged to this area or not. He made the game first with a single rule which was not interesting for him to play and he then generalized it so the computer would randomly pick the rules and it would be a challenge for him too. Creating games like these not only help children understand the concepts better, but in testing it add to the rigor of learning the concepts well. Just as Diva had been inspired by a game made by others, 8th graders were inspired by Diva's game to understand how it works and learn about sets even though they did not yet have it in their syllabus. At STEM land we have sessions where children share their projects once a week to encourage such learning.

To be capable of doing the kind of project above children at STEM land like Diva learn scratch by making smaller projects, through peer interactions and through interactions with facilitators. This is generally need based and strong in some areas and weak in others. To make their skills in all areas rigorous we conduct organized courses at STEM land.

These courses were based on developing basic understanding of various capabilities of scratch programming to allow children to create more complex code.

After completing one such course a program relating algebraic identities with area was built by a few 8th graders. For example, Jan made a program that drew (a+b+c)2 as three squares i.e. a2,b2,c2, and 2ab, 2bc, 2ca as areas of rectangles. Images such as these were also available in the text book. The images in the book, however, were static and used a fixed value of a, b, c. Then as they changed the values of a, b, c to be variable and random they could see the different sizes still held the fundamental shape of a rectangle to get a sense that these were really variables.

Pond EBD: The second case study is in Isai Ambalam School with real life projects. The children had created a pond (Iyyanarappan a, et al 2019) through which they had learnt measuring length, perimeter and calculating circumference, volume of the pond. While creating mortar they learnt proportions and ratios in order to create the right mixture of sand and cement (3:1). However the pond developed some cracks due to roots from trees nearby. Children came together and built a frame in the shape of the pond and through this they learnt to bend metal rods(6mm and 12mm) at specific angles such as 900 450 etc. They also learnt unit conversion from inches to cm for buying the appropriate rods and to cut them in right dimensions. Once the frame was done, they mixed RCC (ratio 1:2:3; cement: granite gypsum: sand) and poured into the structure filling all the rods and finally smoothened it. Through this process they learnt angles and frames as well as ratios and proportions with more than two quantities. We observed children who are less engaged in academic classes are enthusiastic in building with their hands. In this example we have looked at building technology as a way for children to learn.

Shop EBD: In Isai Ambalam School the 7th and 8th graders had difficulty understanding profit and loss. On looking at the prices of stationary in the shops around they found that the price varied and the local shops in the village were charging too much. They also noted that it was not always easy for the young children to have access to shops for small items they needed like pencils, erasers, scales, notebooks that their parents were not always able to provide at the required time. To move from dependence to interdependence at the school they started a small shop of needful things during recess. They raised the investment for this shop as a cooperative among children and teachers and bought items in bulk from Pondicherry and found that they could provide the same items to the children at a cheaper price than that of any local shops. They started the shop in July and it has been successfully running accounting for all costs including transportation. This stationery shop not only taught the children about profit and loss, but also keeping stock, writing receipts and understanding how shops price materials.

CONCLUSION

Creating projects provides children with a way to demonstrate their learning and offers alternatives to examinations as a form of assessment. Furthe r, it offers an opportunity for self-evaluation and constant progress. Through real life challenges aided by physical technology e.g construction, children can learn a lot even beyond their curriculum and connect theory to practice.

Visual technology like computer can be used for programming and helps children learn conceptual ideas better as they need to break it down into small bites of step-by-step instructions for a computer. Creating visual representation also helps them understand abstract concepts. Learning programming builds rigor as they also repeatedly test their programs.

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Notes:

SCIENCE TECHNOLOGY ENGINEERING MATHEMATICS (STEM) LAND: DEEP LEARNING OF MATHEMATICAL CONCEPTS THROUGH EBD AND BY USING MATERIALS

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Abstract: This is an action research project in which we describe deep learning of Mathematical concepts in children through using materials and by Education by Design (EBD). For this paper we define deep learning as: a) ability to apply what they learn in different contexts, b) ability to retain the concepts they learn from term to term or across grades, c) ability to connect what they learn with what they deeply care about.

The two methods described are a) use of physical materials to learn abstract concepts, b) creation of projects through Education By Design (EBD).

EBD is a process of creating projects for learning or to demonstrate learning of a concept. In this paper we will focus on real life problems. We also describe how these EBDs have altered the norms and functioning of the school.

CONTEXT

Education by Design (EBD): An EBD (Mobilia, 1998)

> is a classroom dynamic that guides the thoughtful design of learning experiences for students. In an EBD classroom, students frequently work collaboratively to achieve desired results (for example solutions to real life problems) as they develop knowledge and understanding, critical skills, and vital habits of mind.

In EBDs inquiry methods and self-evaluation are frequently employed.

STEM land comprises of a team of youth engineers who teach in rural STEM centers run in two outreach schools of Auroville – Udavi School and Isai Ambalam School. The engineers were born and brought up in and around Auroville and volunteer part time in both the schools. Both schools aspire towards the holistic development of the child and cater to children from villages surrounding Auroville.

This paper primarily focuses on the younger group of 68 children from 3rd to 7th grade at Isai Ambalam school (age group 8-13 years). Isai Ambalam School follows the central board syllabus and we work intensively with the children for 6 hrs/week during the Environmental Sciences (EVS)/Science and Mathematics classes. In demographics, the occupation of parents at the school is unskilled labor (35%), skilled labor (55%) and salaried workers (10%). The predominant community (45%) accessing the school is SC (Scheduled Caste) which are communities that are socially disadvantaged. Most parents of these children have not completed the 8th standard.

PHILOSOPHIES OF STEM LAND

At STEM land we follow the three principles of true teaching by Sri Aurobindo (Aurobindo, 1910). One, **Nothing can be taught** and the teacher is not an instructor or task-master, but a helper and a guide who shows the child how to acquire knowledge for him(/her)self. Second, Mind **needs to be consulted in its own development**: working with student initiated projects or student questions are good examples. Third, to **Work from near to far**: from the concrete to the abstract, from the known to the unknown. These principles are well aligned with a constructivist philosophy. The name STEM land is in reference to Mathland (Papert, 2002) as spaces where children would learn Mathematics through the provision of appropriate materials these include materials that children can access on their own, as well as tools to create their own projects. Our progression towards meeting these principles is described in this paper.

LITERATURE ON MATHEMATICS EDUCATION

The dislike and fear of Mathematics in children is well documented in literature (Daniel, 1969). The underachievement of children especially from rural and disadvantaged backgrounds is further documented in literature both nationally (Banerjee, 2016) and internationally (Howley and Gunn, 2003).

This is an action research project, as the research has been conducted by the teachers themselves. The purpose of this work is not to analyze children's limitations, but to describe what helped us become more effective in the hope that it will be useful for others. The paper also briefly notes how the functioning of the school itself has transformed through working on real life challenges using philosophies of EBDs.

Our aim is close to the NCF (National curriculum framework) 2005 (Pal Y, et al., 2005) that describes how Mathematics education should address the "higher goals" of broadening the child's mind to help Mathematize (or think Mathematically) and build critical skills like problem solving and logical thinking while addressing narrow goals of knowing skills in Mathematics. The NCF 2005 further states that "Learning should be made enjoyable and should relate to real life experiences. Learning should involve concepts and deeper understanding." In further references (Mayer, 2002) we find that the goal of instruction should emphasize objectives that include cognitive processes associated with "Understand, Apply, Analyze, Evaluate, and Create". These goals are similar to those of Education By Design.

In this paper we describe the interventions that led us towards real life EBDs that helped us learn more about how children learn deeply - retain, apply concepts and also connect with what they care about, and fundamentally alter some of the norms at the school.

LEARNING WITH TEACHING MATERIAL

High School Survey of Student Engagement (HSSSE) found that creation of learning materials could possibly engage children more filling the engagement gap (Yazzie-

Mintz, 2009). Further research suggests that engaged students are better able to make an effort to comprehend complex ideas or master difficult skills throughout their education (Fredricks, et al., 2011).

We noticed the difficulty that children were having with learning in a didactic setting and introduced materials. In specific, we tracked the use of Ganit Rack to automatize addition and subtraction up to 20, Vaughn to master the multiplication tables. In both cases, we were able to see an improvement in the interest of children to engage, and ability work independently or with peers without direct engagement with teachers. With the Ganit rack 8 out of 12 children from the 3rd grade class wanted more problems from the teacher and later solved their own problems. They started seeing patterns of 5 they had not noticed before. We worked with 16 children (4th and 5th grade) who had not been able to master multiplication tables and they appeared to be able to master these with the use of Vaughn Cube. On re-assessment, after 6 months, the children asked for a quick refresh (1 day) after which 14 children had retained the tables. Few of the children were able to answer in the context of the Vaughn cube but had to be supported to correlate this method with their multiplication tables and its application. Deep learning was only partially met in retention supported (with scaffolding).

MAKING LEARNING MATERIALS

We looked at children making their own learning materials rather than using readymade ones. In specific we looked at three, making their own 1m scale from wood and 1m^2 square from chart to understand length and area and creating materials for comparing triangle and square areas with ratios. A 6th grade girl said that she was thrilled to use the hacksaw and cut the wood for the first time. The concepts of conversion from 100 cm to 1m and 1000 cm^2 fit into a 1m^2 were understood and retained over time. When creating scaled rectangle and triangles they noted that a (right) triangle is half the area of the rectangle with the same base and height and the areas scaled as squares of the sides. 18 of 22 children said learning with materials (creating and making) helped them understand and retain concepts better. We noted that on being asked where they could apply mathematics in their daily life the responses of children were in most cases still limited to purchasing from shops. We needed to do more to connect what they did with what they cared about.

REAL LIFE EDUCATION BY DESIGN (EBD)

When faced with acute water shortage at school children began to want to what happened to it. They started to learn about ground water, its depth and discuss in groups the reasons behind the shortage of water, came up with hypotheses and looked for ways to confirm them. They designed an instrument to measure the depth of water. This required some electronics and real life measurements and they started connecting what they learn in school with real life. They studied the water cycle (science) and different kinds of soil to understand ground water and created bunds across the school to increase water recharge.

They also built a pond to have a sense on abundance even in times of difficulty. They found that they needed to learn to work as teams to be successful at such projects and the need for more time to accomplish them. They students asked to come to school on Saturdays for projects and started staying at the school once a week. The school was primarily meant as a day school and lighting at night was limited, children built torches and set up light fixtures. They found that the when the bore well runs sometimes water fills and overflows, they created a sensor for overflow detection. They also looked at recycling the kitchen waste water and created a kitchen garden. The children look at the issues in school as an opportunity to be creative and solve them and take up field work such as painting, digging, masonry, plumbing, planting along with the teachers.

Measurements whether of wires and cables or for the pond they built were made with intent. Conversations on ratios of sand with cement became normal. English was written to describe their observations meticulously. The younger children who were not able to write in English wrote in Tamil first and then translated it into English and learned to present bilingually. The learning was thus integrated over many subjects.

In a survey of 22 children in Isai Ambalam school who were asked where they learn more (1 – class, 5 – both, 10 –EBDs) the average was 6.6. After 6 months of completing an EBD when asked about what they remember children were able to remember materials used for building the pond, many were able to connect mathematics they learned – ‘measurements, ratios, multiplication, division, addition, subtraction'. They were also able to describe skills like ‘process of painting in one direction to get a good finish’, 'how to make a raised bed’, ‘how to grow plants without using chemicals'. The response of how accomplished they feel after EBDs averaged at 8.4 on a scale of 1 to 10.

With stay overs and Sat school the didactic set up of the school has been significantly altered. This increased interactions between children the teachers on Saturday and in the evenings. Even though there was resistance especially for girls to stay over, this has more or less become a norm at the school. Due to the increased inputs from the children many unused area of the school have come to life. An overall improved perception of the school has led to an increase in enrolment of 40% of children with more diversity and a better mix of communities. The survey of the new parents pointed towards them noticing improved confidence and communication skills in the current children.

CONCLUSIONS

We found that while children tend to be more engaged in learning when they use materials, yet the learning is not necessarily deep. However, real life EBDs allow children to take up something they care about, apply their learning, and retain it longer leading to deep learning. Creating their own learning materials seems an intermediate between the two. Engagement with real life EBDs transformed the school from a more didactic arrangement to student-centred living learning environment. The children's ability to work in teams and their communication skills have increased evidence of deep learning and have been acknowledged and appreciated by the communities served by the school.

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