Spring | 2011

Robotics as a Means to Investigate Children's Computational Thinking and Choosing & Valuing as a Social Driver for Learning

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The Amir Lopatin Fellowship Grant Report

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Overview

As described in my proposal for the Amir Lopatin Fellowship in May 2010, I set out to study what "Computational Thinking" looked like in context among K-12 students, as well as choosing and valuing as a social driver for learning. The context for both these inquiries was a week-long Robotics and Engineering workshop in Bangalore, India over the summer of 2010 in which 10 middle and high school children participated. With the help of LSTD faculty Professors Roy Pea (who is also my doctoral advisor), Paulo Blikstein and Brigid Barron, I designed the workshop as well the research based on design-based principles of learning. I also acquired all the materials necessary to conduct the workshop and collect the data here in the US before I left for India in June 2010. The research used various data artifacts to answer the research questions – the chief among these being a pre-post interview, end-of-day reflection memos written by students, as well as audio recordings of whole-group "circle-time" discussions. A mixed-method study emerged as the data was analyzed both qualitatively as quantitatively. A very happy end note to this research study: A 2000-word paper proposal dealing with the first research question on "computational thinking" in K-12 students was submitted to the American Education Research Education (AERA) – the largest education research body in the U.S. The paper was accepted and will be presented at the conference in New Orleans in April 2011.

The following sections describe the study in detail. In the interest of clarity between two very diverse questions that were studied through this research, after a common introduction to the problem space and the research methods, the report will deal with both questions separately as appropriate.

Introduction

"Computational thinking" is increasingly being viewed as an important ingredient of STEM learning in K-12. STEM is clearly center stage for policymakers, curriculum designers as well as researchers. A 2008 report commissioned by the National Science Foundation advocates for investigation into "simple steps that can be taken to introduce computational/algorithmic thinking" in K-12 (Borgman et. al. 2008). Jeannette Wing avers, "computational thinking is a fundamental skill for everybody, not just for computer scientists. To reading, writing, and arithmetic, we should add computational thinking to every child's analytical ability" (Wing, 2006, p.33). Henderson et al (2007) contend that "computational reasoning is the core of all modern Science, Technology, Engineering and Mathematics (STEM) disciplines and is intrinsic to all other disciplines" (p. 195).

There is widespread agreement that in a modern economy that is heavily influenced by technology, computational thinking (CT) supports inquiry in almost all disciplines ranging from art and movies to medicine and biotechnology. There is, however, lesser

consensus on what form CT should take in K-12, and therefore what curriculum would foster such learning and thinking. Early notions of CT which focused on procedural thinking and programming (Papert 1980, 1991), while still considered valid, are now being revisited and broadened to encompass several core concepts of computer science that take it beyond "just programming" (NRC, 2010). While there is still lack of complete clarity on a universally accepted definition of CT, a working definition of describes computational thinking as the reformulation of seemingly difficult problems into something a human can know how to solve by drawing on concepts fundamental to computer science (NRC, 2010). Topical interest in this theme is evidenced not only through features in mainstream media (Lohr, 2009) but also workshops held under the aegis of the National Research Council that have drawn on the collective wealth of expertise from academia as well as industry in the US. The study described in this paper explores ideas presented in these workshops, the proceedings of which were published by the National Academy of Sciences in early 2010.

Since 2008, I have been introducing children to foundational ideas of computer science and computational thinking – ideas grounded in my own background in computer science and education, and experiences as an educational technologist working with teachers in schools and with children in after-school robotics workshops. In an article titled *Computer Science Not Just for Big Kids* (Grover, 2009) published by a leading ISTE periodical for practitioners, I shared simple curriculum ideas for teachers to introduce children to ideas of computing. This project represents an exploratory descriptive research aimed at developing a better understanding of this domain through empirical study of the nature and *language* of CT that is communicated by middle-school age children through participation in a hands-on robotics and engineering workshop intervention. It focuses on dimensions of CT that students are able to express through engagement with computational ideas in robotics. Findings from this study will aid in furthering empirical understanding of what specific aspects of CT are likely to be subject to improve over the course of such interventions and through such curricula, and what tasks may be sensitive to diagnosing these changes. This would put researchers in a stronger position to study development of individual CT dimensions in school-age children.

Dimensions of Computational Thinking – Research Question #1

As a study situated in an emerging space for academic inquiry, ideas for framing the research in a robotics and engineering workshop setting were drawn from recent thought and scholarly work on CT in school education. Repenning et. al. (2010) suggest CT courses such as game design and robotics as a means for gradual and iterative exploration of transferable computational thinking patterns. Robotics also encourages kids to think creatively, analyze situations and apply critical and computational thinking and problem solving skills to real world problems. (Resnick, et. al 1996, Bers 2008). The low-cost, affordable, open-source Gogo board designed at the MIT Media Lab (Sipitakiat, Blikstein, Cavallo, 2002) was the robotics platform used for the workshop.

Fletcher and Lu (2009) contend, "Proficiency in computational thinking helps us

systematically and efficiently process information and tasks." (p. 23) Systematic processing of information is thus an example of an aspect of CT for which evidence could be sought in order to examine CT in students. In order to operationalize CT and define what CT proficiency means in action, the study thus drew on several *dimensions* of CT that emerged from the Workshop on The Scope and Nature of Computational Thinking (NRC, 2010). These include computational concepts such as use of precise language and detail, symbol systems, abstractions and representations, algorithmic notions of flow of control, task breakdown, iterative design, conditional logic, debugging, and systematic error detection, among others.

Furthermore, Fletcher and Lu (2009) describe the notion of *Computational Thinking Language* (CTL) as the glue to connecting foundational concepts of the science of computation. They argue that through exposure to appropriate curricula, students will become accustomed to thinking and communicating in CTL, and this would then provide a more solid foundation for the understanding of Computer Science as well as more advanced programming.

The benefits accruing students from appropriation of academic language as described by Fletcher and Lu (2009) is one that has been researched extensively in the context of science education and ELL classrooms (Lemke 1990, Roth 1996, Chamot & O'Malley, 1994). In the realm of mathematics education, Khisty & Chval (2002) discuss making "mathematical speaking" a critical part of math learning. "Revoicing" student language to academic math language by teachers has been influential in math pedagogy. ""Revoicing" by teachers in classroom group conversations creates participant frameworks that facilitate students' "alignment" with academic tasks and their socialization to roles and identities in intellectual discourse" (O'Connor & Michaels, 1993). More recently, in a chapter titled *How (Well-Structured) Talk Builds The Mind*, Resnick et. al (2010) discuss the importance of academic language in a successful discursive classroom. They suggest that sense-making and scaffolded discussions in math and science classrooms call for particular forms of talk, which are "seen as primary mechanisms for promoting deep understanding of complex concepts and robust reasoning. Multiple studies in mathematics, and to a lesser extent science learning, have demonstrated the role of certain kinds of talk for learning with understanding." The authors proceed to cite more than a dozen papers over the decade from 1996 to 2006 that have dealt with this topic. In the context of science education, Roth (1996b) asserts that new vocabularies give students tools for doing and describing things that were previously not possible for them. Lemke (1990) recommends that to learn science, students need to participate in using the language of science, and through '***talking science***', students learn the shared vocabulary of the discipline and a community of people who share common beliefs, which in the context of this research would be the community of computer scientists.

Unlike a lot of the work on classroom discourse, which extends to gestures, pictorial representations and more, thus study focuses on the spoken words of students in response to questions posed to them. The study thus seeks to examine the development of CT and CTL through *verbal descriptions* provided by students during an educational

intervention conducted with the following guiding research question –

What are the different types and elements of computational thinking language that students are able to communicate and how are they influenced by engagement with computational ideas in robotics?

Choosing & Valuing, Engagement & Empowerment – Research Question #2

Computational literacy is believed to be a new literacy (diSessa, 2000) and a means to empower children in true Freirean spirit (Blikstein, 2008). Blikstein's ideas of critical pedagogy in computational tasks as a means to empower children are evident in the learning paradigms afforded by robotics. The work of Sipitakiat, Blikstein & Cavallo (2002, 2004) with the Gogo board especially in underserved communities in Brazil and Thailand served as a model for this 'Robotics & Engineering' workshop for middle and high school children in urban India, where the same low-cost, open-source platform was used. This paper reports the findings of an exploratory, descriptive research conducted during that workshop with the goal of studying –

a. Students' experiences in a learning environment consciously designed to foster student choice and empowerment through learning activities, and
b. Values that influence the projects children choose to work on in such a setting?

"Science arises in contact with things, it is dependent on the evidence of the senses," (Farrington, 1949, in Resnick et. al, 2000). The transparency in the tool and the programming environment afforded by the Gogo Board allowed students to be involved at a level that would not have been possible with other robotics kits such as the popular Lego Mindstorms. This platform provided opportunities to incorporate choice and skill building activities into the workshop design as a means of empowering students (Saye, 1997; Warschauer, 1996). Programming in Logo, soldering, and working with electronic circuits were skills acquired by students in an authentic context - that of building final projects of their choice with a teammate of their choosing.

Research Methods

Since the research question driving this study aims to look at students' knowledge, use, development and expression of ideas of computational thinking in the course of working on projects and problem-based tasks in the robotics workshop, structured clinical interviews conducted before and after the workshop were the main data measures.

Participants

Eight middle school and two high school students (mean age ~13 years) signed up to participate in a week-long robotics summer camp-style workshop in June 2010 held in a school in urban India. The students did not know before the workshop what exactly they would be doing in the course of the workshop, and were not aware of the study when they signed up for the workshop. All students participating in the workshop were recruited to participate in the study just prior to the start of the workshop.

Procedures

The workshop and study were conducted over a period of 8 hours per day for 5 days. The author (who was the sole researcher) facilitated and led all the workshop activities as well as the data collection effort. An assistant who shared the workload of helping students during workshop activities and execution of final projects accompanied the researcher.

Table 1 below describes the broad schedule over the course of the five days. Each day started with a facilitator-led "circle time" where the whole group discussed work from the prior days and looked ahead to the agenda for the day. At the end of every day, students wrote individual reflections in response to prompts that urged them to reflect on the day's activities, learning, challenges, accomplishments and a-ha moments.

Table 1. Schedule of the 5-day robotics and engineering workshop

Day 1* – first half	General introduction to robotics; a demonstration of a Gogo board musical toy designed by the researcher; a show and tell of sensors, motors and other input/output devices
Day 1 – second half	Introduction to Logo programming
Day 2 – first half	Students program the Gogo board using appropriate Logo commands, and experience the sensing and reacting behaviors of the Gogo board in action
Day 2 – second half	A brief explanation of the Gogo board circuitry and a tutorial on soldering. (This was to build in children the capability to solder Gogo board connectors to the sensors and output devices that they would need for their final projects.)
Day 3 & Day 4*	Students work in pairs designing, programming and building the final project installations of their choice.
Day 5	Students wrapped up testing their final projects, made posters and finally

	presented their projects to the families of all the participants who were invited guests for the final presentations.
* Pre/post interviews - Students are individually interviewed before the start of day 1 and at the end of day 4. Students' responses were video recorded in both instances.	

The following brief description of the five final projects serves to give a sense for the level of computational complexity that was involved in the open-ended design and programming efforts of the final projects.

- An Automatic Juice Dispenser - using a conveyor belt which stops when a cup is detected at the juice pump, dispenses juice and moves on;
- An Energy Efficient Home – with a water storage and shut off system, and an energy efficient lights and fan system;
- A Home Security System – consisting of an automatic gate, and different alarm systems that are activated by motion and pressure, and deactivated by voice;
- A Smart Safe - where keys pressed in the right order open the safe; else they trigger flashing LEDs and an alarm; and
- A Smart Car - which avoids collisions based on its IR sensors

Measures

- **Survey of prior experience**: To capture a detailed account of the students' background and prior technology experiences, a survey was administered measuring experience with many activities that reflect traditional technology fluency-building potential, such as programming or building a website (Barron 2004). *(Research Questions 1 & 2)*

- **Pre/Post interview**: Prior to the beginning of the workshop, and again at the end of day four, each participant was shown the Gogo board and asked the question ***"If I told you that this was the system that made a robot work, what do you think it***

does?" Students' verbal responses in these pre-post interviews form the bulk of the data that has been analyzed for this paper. *(Research Questions 1)*

- **Individual reflections** written by students at the end of days one through four in reflective journals provided to each student. *(Research Questions 2)*
- **Audio-taped conversations** during whole group "circle time" at the beginning of each day were captured and were examined to glean further insights into students' developing notions of computational thinking as well as their affective attitudes towards the workshop and their experiences. *(Research Questions 1 & 2)*

Data Analysis & Results – Research Question #1

Following transcription of the pre and post interviews, coding and analysis was inspired by techniques of verbal analysis outlined by Chi (1997) with the aim of analyzing qualitative data in an objective and quantifiable way. A coding scheme was developed to refine dimensions of CT into taxonomic categories which represented different types of ideas in realm of computing, such as broad concepts, CT principles, CT jargon and vocabulary, and lastly, procedural and operational ideas of computation.

These taxonomic categories of Computational Thinking are described below (with examples of each):

Code	Category Description	Examples	Example Quote
CTC	CT Broad Concept (may or may not use CT language)	Programming, Automation, Storage of data	*"does what it is programmed to do"; "works as the brain and a controller.."; "it can also remember actions or programs"*
CTV	CT Vocabulary (CT language)	RAM, input, output, software, download, program, memory, debugging	*"collecting inputs first .. there are certain input devices like sound sensor"*
CTPro	CT procedural/operative details	Turn power switch on/off; download a program from the computer to the robotic controller via a USB cable…	*"You connect it to a computer and you use a programming language such as .. LOGO .., download the program, and it gets saved in here "*
CTTT	CT Technical Terms	Processor chip has RAM to store data; the processor chip is the "brain" of the controller	*"device which basically converts voltage or changes the voltage.. here's ..where the power supply is – (turns it over) 6 batteries or.. 9 volts"*
CTPri	CT Principle (Dimension)	If-then conditional; task decomposition; abstraction; error checking; debugging	*"if there's some sort of pressure sensor and the output is some sort of light; when you push the sensor the light comes on "*

Findings indicate a substantial quantitative as well as qualitative increase in Computational Thinking Language as communicated by students in response to the same question before and after the robotics workshop. On average, students made mention of about 14 ideas related to computing in the interview prior to the intervention. This figure

more than doubled to about 32 in the responses post intervention. The most dramatic individual response featured a jump from 1 to 32 utterances. The most dramatic increase among the categories along which the data was coded, was in CT principles, and the least in broad concepts of CT. CT vocabulary more than doubled, from 54 words/phrases in the pre-interview responses to 134 in the post-intervention interviews.

Pre-workshop responses were restricted mostly to broad CT concepts such as automation (for example, "robots make our life easier") and programming a machine, as well as some vocabulary of the domain, although most vocabulary were restricted to common words like *program* and *programming*. However, pre-interview responses made no mention whatsoever of computational principles like *abstraction*, *task breakdown*, *precise instructions and sequencing*, *conditional logic*, *error checking*, or *testing*. Post-workshop responses, by contrast, made mention of an average of between 3 and 4 computational principles (average of 3.5), the most common ones being *conditional logic* (*if-then* or *when-this-then-that*), *task breakdown into step-by-step instructions*, *precise instructions*, and *sequencing of tasks*. These responses were richer not only in more specific notions and principles of computing, but vocabulary as well (*input*, *output*, *download*, *memory*, *storage*, among others), which increased from an average of about 5 before to about 14 after the intervention, thus signifying development of CTL along various dimensions. Even the category that showed the least percentage increase – broad concepts of CT, registered a jump from 44 to 55 occurrences in the pre- and post- responses respectively.

Statistical *t-tests* on the pre and post intervention mean occurrences of all categories of CT language, barring *Broad Concepts* were statistically significant. The graphs below show the total occurrences of CT Language by CT category in the pre-post responses for all subjects, and a subject-wise breakdown of the percentage change in total CT Language communicated in the pre-post interviews.

Table 2: Total Occurrences of CT Language For All Subjects Across All CT Categories in the Pre-Post Interviews

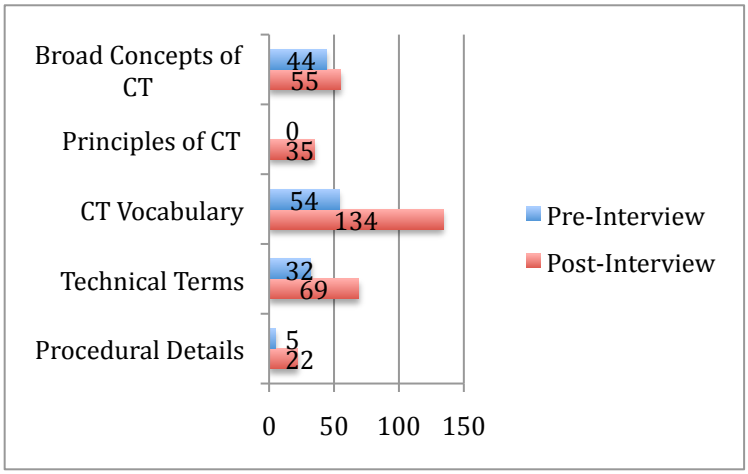
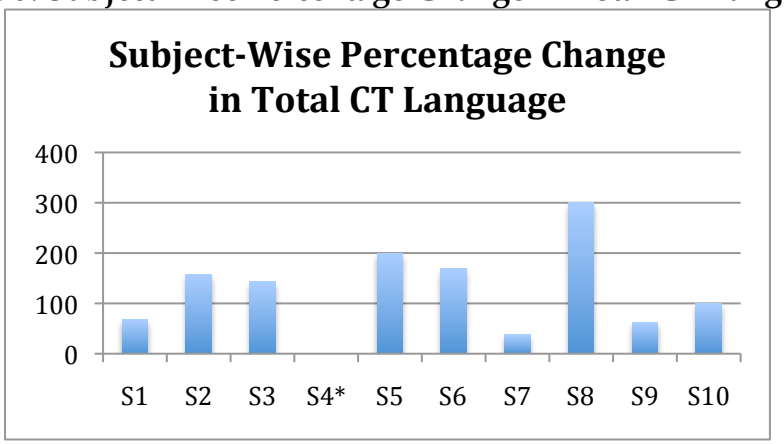


Table 3: Subject-Wise Percentage Change in Total CT Language



** S4 registered a 3100% increase in CT Language mentioned in the pre-post response, and could not be graphed with the rest.*

Closer scrutiny of the data also revealed no significant interactions between the frequency of occurrences in different categories, except for an inverse relationship between the frequency of technical terms and CT principles. The two students (S1 and S9) who mentioned the most technical terms (average of 16) in the post interview were also the ones who touched upon the least number of computational thinking principles (average of only 1). This is evidenced in the graph below. Some illustrative snippets from students' pre and post responses are provided in Table 5 below.

Table 4: CT Category-wise breakdown of post-responses for each student

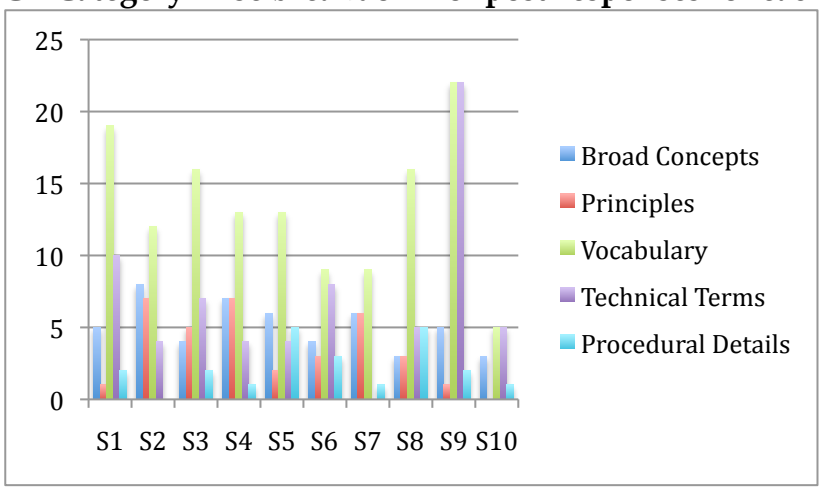


Table 5: Examples of responses to a question about a robot controller before and after the workshop.

	Pre-workshop Response	Post-workshop Response
Student A (11.9 years)	*- It's the programming device – when you download the programs into it, and it's the one that controls the robot and*	*- I would say that it is the brain, otherwise known as the controller, which is programmed from the laptop, or any computer with the software in it. When you enter a command into it, for example if you attach a light sensor and*

	monitors the actions and procedures done by the robot..	*say 'to sound forever beep end' so it'll do the exact same thing* *- You first break your program into tiny steps and first try it out because if you put everything all jumbled up in one if it doesn't work you don't know where you've done your mistake..and you won't be able to correct it..so if you break it up step by step..*
Student B (13.8 years)	*- It makes a robot move.. solve problems…Then it…I don't know..I'd say that it helps..it can also help other people do things..*	*- It makes it respond to certain stimuli..* *- We use programs to do that (monitor sensor values) .. and also there are these different programs for different things and we used a program called Logo. There are many many others but we used Logo…Logo- it just makes this thing called the gogo board do anything like depending on what sensors it has attached .. if it senses x then output will do y...* *- Even though robots might seem all complex with all those wires poking out there and everywhere, it's actually really easy once you break it down into small pieces..*
Student C (14 years)	*- I don't know..I have absolutely no idea what it would do…* *- It's .. a robot. A .. working.. artificial uhh.. device. Yeah.*	*- To program it you could use different types of softwares or languages... And you would follow it all like step by step procedure .. checking each – each sensor is working correctly and then what it's doing to make the output happen.*

Data Analysis & Results – Research Question #2

For the second research question on empowerment, choosing and valuing, the primary data used were the entries made by the students in their reflective journals at the end of each day, as well as a whole group conversation at the beginning of Day 3 that was audio-recorded. The coding scheme for data analysis was inspired in part by the elements of empowering learning environments as described by Warschauer (1996).

Focus on post-workshop data analysis thus far has been on research question #1. However, preliminary findings reveal evidence, to varying degrees, of choice, values, identity, autonomy, and skill building, among others, linked to specific activities and experiences. Three out of the five final project descriptions reflected choices closely linked to students values, whereas the remaining two projects showed evidence of strong student background and interest.

The following is are a few demonstrative snippets from conversations and individual reflections—

- *"I don't like computers at all…and… now I think it's really useful. Like I didn't know soldering before and I'm really scared of fire and burning and all those things, and I finally got to know how to use it, and I, I'm not afraid anymore…"*

- *"I learned how to solder wires together but before this I never knew how to solder..and yeah.. I also learned how to program with the Gogo..uhhm, I never .. I used to program with an NXT before, … it used to come in sets so we didn't have to start from scratch but in the Gogo you have to all by yourself."*

- *"The most fun thing of the day was constructing, programming, and testing. We really felt like pro engineers."*

- *"I never used the flux before so I learned what that is..and I never even realized that it could be extremely helpful when you're doing it..because when you put it on..the lead just adheres to the wire.. I don't know how - it just adheres to it, it's extremely annoying to do it without it now..I just can't use it..I can't use the soldering iron without the flux now.."*

- *"I personally feel that this was the best day in the workshop, because we surprised ourselves with how much we learned over the last three days."*

I aim to complete a more exhaustive analysis of this data for evidence of accomplishment, identity, and empowerment from skills development. In a paper I hope to submit for publication, I plan to include an illustrative case study of a 12-year old female participant.

Discussion & Conclusion

As evidenced in the data and analysis of research question #1 as described above, through engagement in the robotics workshop, students' computational thinking as expressed in response to the same question not only grew substantially but also belonged to various categories. These "types" of terms and phrases used include broad concepts of computational thinking, vocabulary and terms belong to the domain, as well as core principles and dimensions of computational thinking, perhaps the most relevant as far as deeper ideas of the science of computation go. Some less relevant types of terms and language, such as technical terms of the robotics board, and procedural and operational details of the use of the specific technology, were also expressed.

Also, in support of the belief that CT is not only about computers (Lu and Fletcher, 2009), there was evidence, albeit only in a couple of responses, of CT themes mentioned in connection with tasks outside of programming, such as sequencing of design activities for the final project. This is an area that merits further investigation, as a key goal of building CT is to promote transfer to other professional and intellectual endeavors, and everyday life itself (Lu & Fletcher, 2009)

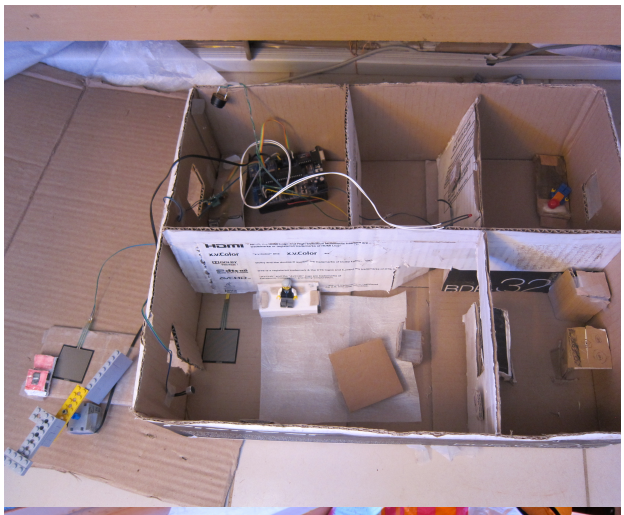
In response to research question #2, this exploratory study proved to be illustrative of the types of activities students find particularly empowering and engaging in the course of performing computational tasks, and contributes to the emerging area of computational literacy and how critical pedagogy can inform the design of future learning environments that empower as they engage.

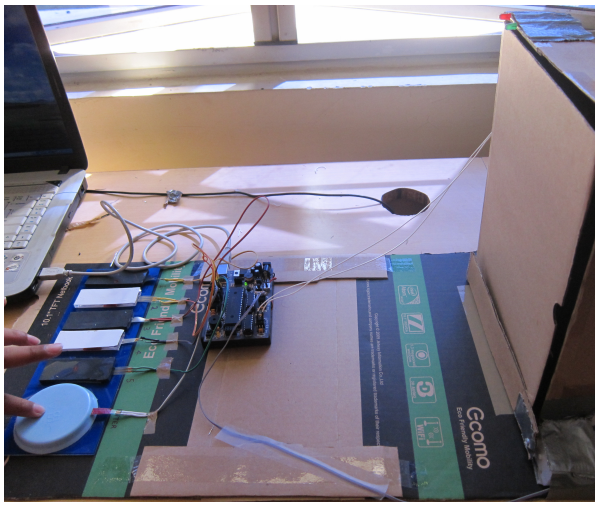
To summarize, while this descriptive study was limited by a small sample size, and as such its findings are not generalizable, it is illustrative and provides a foundation, and direction, for much needed further work in the emerging area of building computational thinking in school-age children as well as empowering children through computational literacy.

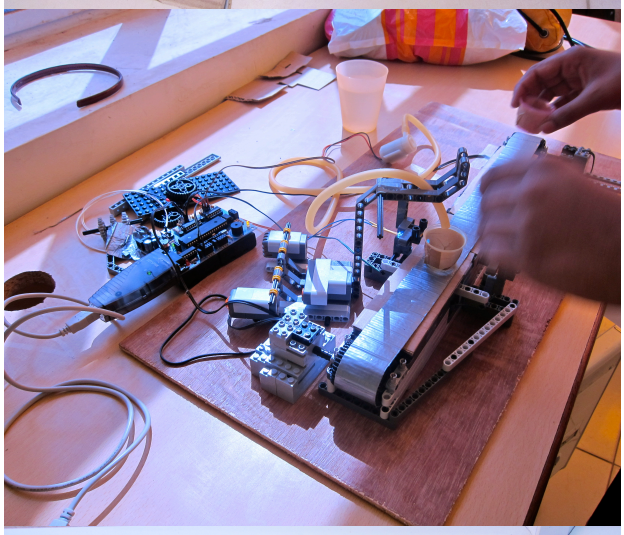
Closing Thoughts

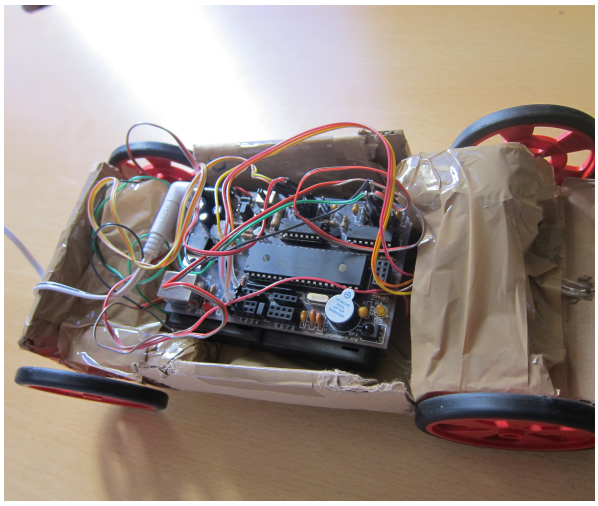
The Amir Lopatin grant allowed me to equip myself with all the necessary materials as well as personnel assistance to make this research possible. The purchase of the Gogo board kits, sensors and all the peripheral electronic equipment (such as Keyspan USB-serial port adapters) was done prior to leaving for India. Additionally, since the research revolved around capturing audio and video data, the purchase for all the necessary audio and video equipment was facilitated through funds from the Fellowship. This enabled effective capturing of responses to the pre-post interviews as well as other interactions and conversations throughout the week-long workshop, not only on video, but in the form of audio and image artifacts as well. As sole researcher, playing the main lead on the workshop would have been a near impossible task for me had it not been for the engineer who was able to join me for most of the duration of the workshop to assist with working with the students on their workshop activities and final projects. The fellowship also funded the daily commute to the workshop venue - a school 30 km outside Bangalore, as well as the rental of laptops for the students to work with. All in all, this was a valuable and enriching first year research project experience for me, and for that I am thankful to the generosity of Amir Lopatin's family and friends.

APPENDIX – Picture Gallery of Final Projects









References

Barron, B. (2004). Learning ecologies for technological fluency: Gender and experience differences. Journal of Educational Computing Research, 31, 1-36.

Bers, M. (2008). Blocks to Robots: Learning with Technology in the Early Childhood Classroom. Teachers College Press, NY, NY.

Blikstein, P. (2008). Travels in Troy with Freire: Technology as an Agent for Emancipation. In P. Noguera & C. A. Torres (Eds.), Social Justice Education for Teachers: Paulo Freire and the possible dream (pp. 205-244). Rotterdam, Netherlands: Sense.

Borgman, C. et al. (2008), Fostering Learning in the Networked World: The Cyberlearning Opportunity and Challenge, US National Science Foundation (NSF) publication, National Science Foundation (NSF). Available at: http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf08204 [Accessed July 21, 2010].

Chamot, A. U., & O'Malley, J. M. (1994). The CALLA handbook: Implementing the cognitive academic language learning approach. Reading, MA: Addison-Wesley.

Chi,M.T.H. (1997b).Quantifying qualitative analyses of verbal data: A practical guide. Journal of the Learning Sciences, 6(3), 271–315.

diSessa, A. A. (2000). Changing minds: Computers, learning, and literacy. Cambridge, MA: The MIT Press.

Fletcher, G.H. and Lu, J.J. "Education- Human computing skills: rethinking the K-12 experience," Communications of the. ACM, 52(2), pp. 23-25, 2009.

Grover, S. (2009). Computer Science Not Just For Big Kids. Learning and Leading with Technology, 37(3), 31–34.

Henderson, P.B., Cortina, T. J., Hazzan, O., and Wing, J.M. Computational thinking. In SIGCSE '07: Proceedings of the 38th ACM SIGCSE Technical Symposium on Computer Science Education, 195–196, 2007

Khisty, L., & Chval, K. (2002). Pedagogic discourse and equity in mathematics: When teachers' talk matters. Mathematics Education Research Journal, 14(3), 154-168.

Lemke, J.L. (1990). Talking science: Language, learning and values: Norwood, NJ: Ablex.

Lohr, S. (2009). New Programs Aim to Lure Young Into Digital Jobs. New York Times. Available at: http://www.nytimes.com/2009/12/21/technology/21nerds.html [Accessed July 21, 2010]

National Research Council (NRC), Committee for the Workshops on Computational Thinking. (2010): Report of a Workshop on the Scope and Nature of Computational Thinking. Washington, DC: National Academies Press.

O'Connor, C. & Michaels, S. (1993). Aligning Academic Task and Participation Status through Revoicing: Analysis of a Classroom Discourse Strategy. Anthropology & Education Quarterly. Vol. 24, No. 4

Papert, S. (1980). Mindstorms : children, computers, and powerful ideas. New York: Basic Books.

Papert, S. (1991). Situating Constructionism. In S. Papert & I. Harel (Eds.), Constructionism. Cambridge, MA: MIT Press.

Repenning, A., Webb, D., and Ioannidou, A., "Scalable Game Design and the Development of a Checklist for Getting Computational Thinking into Public Schools," Proceedings. SIGCSE 2010, Milwaukee, WI, 2010.

Resnick, L. B., Michaels, S., & O'Connor, C. (2010). How (well-structured) talk builds the mind. In R. Sternberg & D. Preiss (Eds.), Innovations in Educational Psychology: Perspectives on Learning, Teaching, and Human Development. New York: Springer Publishing Company.

Resnick, M., Martin, F., Sargent, R., & Silverman, B. (1996). Programmable bricks: Toys to think with. IBM Systems Journal 35(3), 443-452.

Resnick, M., Berg, R., & Eisenberg, M. (2000). Beyond black boxes: Bringing transparency and aesthetics back to scientific investigation. The Journal of the Learning Sciences, 9, 7-30.

Roth, W.-M. (1996). The co-evolution of situated language and physics knowing. *Journal of Science Education and Technology, 3,* 171–191.

Roth, Wolff-Michael, 1996b. Thinking with hands, eyes, and signs: Multimodal science talk in a grade 6/7 unit on simple machines. Interactive Learning Environments 4:170--187.

Saye, J. (1997) Technology and educational empowerment: students' perspectives, Educational Technology Research & Development, 45(2), 5–25.

Sipitakiat, A.; Blikstein, P.; & Cavallo, D. (2004): GoGo Board: Augmenting Programmable Bricks for Economically Challenged Audiences. In Proceedings of the International Conference of the Learning Sciences. California, USA, pp. 481-488.

Sipitakiat, A., Blikstein, P., & Cavallo, D. (2002). The GoGo Board: Moving towards highly available computational tools in learning environments. Proceedings of Interactive

Computer Aided Learning International Workshop. Carinthia Technology Institute, Villach, Austria.

Warschauer, M., Turbee, L., & Roberts, B. (1996). Computer learning networks and student empowerment. System, 14, 1-14.

Wing, Jeanette, "Computational Thinking," Communications of the ACM, March 2006, (49, 3) 33-3