Build Robots Create Science –

A Constructivist Education Initiative for Indian Schools

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Abstract

We present an instructional technology initiative from IIT Kanpur and Media Lab Asia aimed at reducing the rote learning component in Indian Education, and shifting the emphasis to more experiential learning through hands-on activities. Part of the interest is generated through building robots, which many children find emotionally appealing.

This paper describes a set of tools and pedagogic methods aimed at the Indian schoolchild, age 10-18, developed through tests at a number of urban schools in Northern India, with increasing exposure to underprivileged and rural schools.

A side benefit of this work is increased social awareness among the workshop conductors, typically upper-class Indian students from Engineering Colleges and privileged urban schools.

Keywords Constructivist Education, Hands-On, Robotics, Rote Learning, Electronics Education

1 Rote learning in Indian Education

I can still recall my first contact with education - a one-room village school in Bengal where a single teacher managed four classes, each of which sat on one side of a verandah, that ran around the square room in the center. A bunch of us six-year-olds would sit under the sloping roof, swaying back and forth holding our slates, and parroting the chant - "two ones are two, two twos are four" etc. As you walked the lanes at night, you would hear voices droning from various lamp-lit windows, reciting aloud facts such as the succession of Mughal empires and the nature of the Monsoon in the Indigoangetic plains. Endless repetition, in a loud voice, was the mantra for eternal memorization - but more likely it merely served to tell the parents that there was serious studying going on. The core focus of education was memorization - the more one could memorize, the more one excelled in examinations.

Fortunately for me, I was soon moved to more enlightened educational practices, but faintly bitter shadows of those days remain with me even now. It is with great sadness that I note that even with increasing awareness of educational practices today, the overwhelmingly large body of schools in India (and many less developed nations) still focus on memorization as their key objective, and societal forces actually encourage it, under the scourge of an examination-based degree and admission system which further emphasize this "mugga" culture.

Figure 1: Toys from Junk: Making a wheel out of a tin can. (BRICS Workshop, Katha Khazana, Govindpuri slums, New Delhi, February 2002).

Historically, there has been a large role for memorization in traditional Indian culture, in the times where books were scarce, and practice-based teachers even rarer. Precise memorization was a premium skill, and scholars were graded on the texts they were able to memorize (e.g. dwivedi = second vedic scholar). While there is a tendency in
discussions of the Indian educational system to blame the British (and especially the reviled Macaulay minute) for all the ills of Indian education, the fact is that when the British introduced an educational system for India, it was not far behind those prevalent in European schools of the time, where didactic techniques far outweighed any constructive or practice-based education. Of course, the fact that the new system was not organically developed but externally enforced may have caused lasting damage to the societal forces that normally would have re-evaluated the educational process. This is certainly part of the real tragedy which happened later - while the European schools underwent continuous evolution and re-design, most third world nations fossilized their systems around the European models imported in the nineteenth century, which have been described as:

"Teaching was by rote and drill. Encouragement was by the rod. Obedience (to God, parent and teacher) was the foundation rock for the mansion of learning)."

[Withers, about American schools in the nineteenth century, quoted in Haury and Rillero 94].

The focus on obedience, and even the occasional resort to violence for enforcing discipline, are familiar traits in Indian schools today, a hundred years after the description above.

We present details of our methodology and approach, after presenting some considerations from cognitive theories of learning.

1.1 Philosophical foundations

The need for direct experience in education has been emphasized for a long time. The divergence between textbook education and real life practice in early twentieth century America led the educational psychologist E.L. Thorndike to argue for education based on skills relevant to real-world application.

Incomplete of knowledge transfer through lecturing and textbook education go deeper than is commonly assumed - the recent Project 2061 initiative by the American Association for Advancement of Science, working to reform school education, affirms:

"Cognitive research is revealing that even with what is taken to be good instruction, many students, including academically talented ones, understand less than we think they do. With determination, students taking an examination are commonly able to identify what they have been told or what they have read; careful probing, however, often shows that their understanding is limited or distorted, if not altogether wrong."

[5]

In recent times, the role of discovery through direct experience has been emphasized by Constructivist theories of learning. Constructivism arose in contra-position to Behaviourism, in which one viewed learning as the process of conditioning observable behaviour through selective reinforcement of an individual's response to stimuli. Closely related was the objectivist position in which the mind started as tabula rasa, and was to be filled with objectively correct facts. This assumption, in fact, underlies the theory of learning from textbooks so prevalent in India today.

The constructivist approach, on the other hand, questions the very existence of an objective reality. Learning is seen as subject to one's prior experience, and one of the positions is that the nervous system cannot distinguish between the sensory stimulus from an external phenomenon and an internal hallucination. Thus there is no objectively correct reality, and all learning is purely subjective. However, this has been questioned, especially in the context of developing a socially accepted world view. The "complementarity between individual construction and societal interaction" has been the subject of much debate between 'radical' and 'pragmatic' constructivists. In terms of educational techniques
however, there is a large degree of consensus on some of the approaches that can be useful, such as guiding discovery through open questions, and increasing use of "manipulatives" (such as blocks or marbles for counting and grouping operations in mathematics), and "hands-on" exploration, (e.g. paper folding). The role of the teacher is more as a "midwife in the birth of understanding" as opposed to being the agent for "knowledge transfer". On the whole, constructivist ideas make little claim of theoretical innovation, but attempt to provide a conceptual structure for guiding educational practice.

This is the thinking that has guided the increasing use of tools for hands-on exploration in education, of which the BRiCS initiative is an example. These go together with other constructivist positions such as student-directed goals, teachers as coaches, self-reflection, learner control, exploration, problem solving, etc. all of which have been part of our model as well.

Another buzzword often heard is related to "vocational education", which emphasizes job skills since much of the workforce is not expected to be in a position to complete even twelve years of schooling. However, while a vocation typically involves hands-on training - indeed, that is what distinguishes the vocational training from mainstream education - the sad fact is that most polytechnics and vocational schools do not have the expensive infrastructure really needed for on-the-job training and again revert to a education model along the sad lines of curriculum driven examinations.

Figure 3: Semi-literate programming Student in Katha Khazana slums (Govindpuri) programming robots. Even students who knew no English were able to read the icons of this visual programming language.

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2 BRiCS (Build Robots Create Science)

BRiCS arose out of interactions we have organized in the Center for Robotics, IIT Kanpur, for various groups of visiting children. The children's fascination with robots and the availability of simple programmable electro mechanical kits like the LEGO Mindstorms gave rise to the idea of introducing simple robotic mechanisms as an educational tool.

Subsequently, the applications of this tool were expanded to themes from Indian Mythology, myths and legends, history, transportation, and many other subjects. As it stands today, the initiative is aimed at the two primary groups:

1. Urban Schools:
   To add hands-on exercises that create excitement in science and mathematics education. A good amount of the interactivity in these exercises will depend on relatively high-cost commercial kits. Increasing numbers of such schools have already set up BRiCS labs which are being slowly integrated into the pedagogic practice across a number of subjects.

2. Rural Schools:
   For this purpose it is imperative to reduce the cost of the tools for hands-on interaction. We have developed a number of "Toys from Junk" activity based on work such as that of Arvind Gupta [3]. Several low cost electro-mechanical kits have been developed. A large challenge currently under way is to develop cheap interfaces for programming.

Also, the workshops have been found useful in other groups – e.g. for Undergraduate Colleges – in introducing them to basic skills in engineering and electronics, among the Design Fraternity as a design conceptualization and rapid prototyping tool for the design, fashion, and engineering communities, and among managers and executives as a Creativity Exercise.

2.1 Modality of a BRiCS Exploration

BRiCS explorations are workshop sessions conducted by students in small groups of 4-5 students, and a BRiCS member as a mentor. The mentor is either an IIT Kanpur student or a student

1 The i in BRiCS stands for interactivity – a key component of the BRiCS philosophy. However, it can just as well reflect an emphasis on imagination and innovation.
from a previously conducted workshop. The coach leads the group in three kinds of exploration.

Typically workshops may be of two or three days. The last hour or two are devoted to an exhibition, where the families and friends of the children, and other school children and staff are invited, hereby enabling the society at large to interact with the models made. Shorter demo workshops for a day or half-day have also been done, but as a rule these are not very effective and we try to avoid such small workshops.

2.1.1 Toys from Junk

Here we ask the kids to look at common place objects in different, creative ways. For this purpose, we carry an assortment of “junk” material to the workshops - used sandal material, bicycle spokes, wire, straws, cardboard/paper, marbles, matches, etc. We use Indian products made by organizations such as Ekalavya or Navnirmiti and ideas from people like Arvind Gupta, Arthur Gansen, etc. It is surprising how many children can’t fold paper well. We demonstrate a number of toys using such products, and encourage them to tinker with them and come up with ideas for other toys. The students are then asked to document their toys in any manner they choose.

2.1.2 Create Robots

Here we use systems such as LEGO Mindstorms, Mechanix, and K’nex. These kits run from Rs. 8,000 to 12,000 depending on the level of duty your organization attracts. This reflects as a cost between Rs. 50-200 per student, depending on the hours of interaction. The kits contain plastic building blocks, electronic sensors (light, touch and infrared), motors, miniature drive components (spur, bevel, and worm gears, shafts), and wheels, joints, fasteners etc. These are controlled through a programmable microprocessor module with simple visual programming software (similar to the LOGO software). The students learn to build these robots initially from some sample models, and then according to their own interests. They practice using sensors, motors, and building blocks like gears, pulleys, levers, etc.

2.1.3 Beyond Toys

The students are introduced to simple electronics circuits such as relays, switches, and possibly, diodes and microprocessors. These are used to control simple functional devices that interact to the environment. Often, the students will integrate these components with the junk and the robot kit to produce novel ideas.

A number of electronics / robot kits and small projects have been developed by us for construction by school students. One of the projects is a wall-hugging mouse built from a spring-loaded switch. Other projects replace some of the expensive sensors in kits like the LEGO Mindstorms. In particular a touch sensor and a photo-sensor kit has been developed which can be built by the students and integrated into the robots they make in the LEGO system. Once they are familiar with these simple projects, they can embark on building a robot from scratch.

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Also, a number of robot building contests have been held under BRiCS and we plan to have more contests to encourage students to carry on with the BRiCS activity even beyond the period of the workshop. We introduce them to national and
international opportunities available to school children for participating in various contests and competitions. For this part, we are also developing an alternative to computer based programming in terms of physically programmable bricks - a set of "smart" bricks, placed in different sequences, results in different programs - obviating the need for a computer.

2.2 Research on Alternative Technologies

A major part of the BRiCS effort is research on developing alternative technologies for low-cost hands-on education suited for Indian schools. At present the following have been developed:

- Programmable bricks: Each brick contains a part of a circuit, which when stacked on top of another creates a sequence of behaviour for a robot. This eliminates the need for expensive computers in order to do the programming, and also enables a physical model for the computer programs used to drive the robots. (Figure 5)
- Wire gears: These are gears and shafts made of MS wire. These very cheap devices can transmit low-torque motions across complex geometries.
- Robot Kits: A wall-hugging robot kit has been developed for Bill of Materials cost of Rs.100. A low cost programmable robot is being developed at prices under Rs.1000. These are given to children for them to assemble and take apart and also for modification, in the "Beyond Toys" module of the BRiCS workshops.

All technology being developed under BRiCS is under the open technology license, which is similar to open software in that individuals (and educators) are charged no money for using these technologies.

2.3 Integrating BRiCS into the school curriculum

We find that these workshops are particularly effective if the students decide on a theme (surprisingly this can be anything from English Literature (we have looked at scenes from Macbeth) to Insect Colonies, Indian mythology, history, fairy tales, or any other ideas they can come up with. They then design and decorate their robots to match the theme, and they also program the appropriate behaviour into them, and present some documentation. The theme provides an anchor around which they develop their ideas of projects to build. Usually, the theme has to do with an area of deep personal interest, such as the livelihood of the children (see figure), or a recently studied topic. At the end of the project, children are asked to document their work and prepare a poster for an exhibition.

Students who participate on a BRiCS workshop on the theme of "Merchant of Venice" or "Indian Mythology" are likely to have a completely different perspective on these topics than achievable in traditional methods.

3. BRiCS business model

At this point, the BRiCS team does not charge any fee for the workshop, which is conducted by IIT student volunteers who teach the children without charge (transportation and local hospitality is to be covered; and for better-off schools, a small contribution is requested). However, setting up a BRiCS lab in the school may be expensive - a lab for 25 students will start at Rs. 10,000 ($200) for a non-robot kit setup to about Rs. 70,000 ($1500) for a fully kitted setup. This is in addition to computers which must also be available for programming etc.

The major challenge in propagating BRiCS in the long run is that of sustainable integration into existing educational practice. The cost of the tools or the equipment is really not as much a problem as we had initially felt; between sponsorships and other means, we have more schools interested in BRiCS than we can possibly engage. The main problem is manpower -- the present model of five students conducting a three-day workshop for twenty-five students clearly cannot be sustained by students from a single institute. Currently the BRiCS team consists of twenty volunteers who run between two to four workshops per month - clearly BRiCS needs to do more.

Figure 6: Wool-knitting machine. This machine was designed by an underprivileged girl whose mother makes a living by knitting. In two days, she was able to develop this wool-knitting machine that takes four strands
of wool in each direction and knits these into a small piece of wool cloth.

Initially we are focusing on students from other institutions and setting up BRiCS chapters in different cities. Alongside, we propose a business model based on unit coordinators, small entrepreneurs who initially work with the more well-off schools and charge a small fee (about Rs 300-500 per child per year) for running BRiCS workshops and interaction sessions during the school week and weekends. In the process, they earn about Rs. 12000 per month for themselves (about $3000 a year), and in cooperation with the local BRiCS chapter and alumnus of previous workshops, conduct about 30-40 workshops yearly to introduce BRiCS into local schools. Thus, the activity becomes a means of livelihood for a group of individuals which is the central requirement in order to make it sustainable in the long term. Annual workshops create a community of learners and develop the pedagogic paradigm which is disseminated to this group. Further spread into rural and weaker schools can be possible through a mix of lowering costs (through indigenized technology), external support (to be avoided as far as possible but unavoidable in certain circumstances) and improved educational paradigms that work with existing curricula. For this purpose, it is imperative that the BRiCS team is building links to other like-minded groups across the country.

3. Conclusion

So far, BRiCS workshops have been conducted in about thirty well-off urban schools across the country, several rural or underprivileged schools, at the Science Museums in Mumbai and Kolkata, etc. Many upscale urban schools have already set up BRiCS labs. The response has been overwhelming at each of these places, and there is a constant clamour for further workshops in these schools.

Based on our experience in India, it seems worthwhile trying this model in other countries in the Asia region. A further boost is in using children themselves as mentors in follow-up workshops. Even rural children, those who do not know English - become amazingly adept even in the programming using icons that are labeled in English. They can even communicate this in Hindi using words like "wait 5", "if sensor A" etc. (Figure 6). We have asked some of the underprivileged students to help us with subsequent workshops and their response, and their performance as mentors for a peer group, has been simply overwhelming.

A surprising benefit of this project has been intellectual opening and growth among the students from IIT Kanpur. These students, who mostly come from privileged backgrounds, find it very fulfilling to be able to light a lamp in the minds of their young pupils. There is no money or academic credit for working in BRiCS. The tremendously loving response they get from the children is their only recompense, and in many instances, this relationship continues through e-mail and letters much after the workshop is finished. In fact, many of our students obtain a high degree of social sensitization through these workshops that they would not have received otherwise.

Among the vast population of India, the human potential remains largely unutilized because the educational system has become disjointed from real life. We hope that initiatives such as BRiCS can make the learning process more creative, interactive, and connected to real life.

Acknowledgements

We acknowledge the support of Kavita Joshi and her team in preparing the Video "Build Robots Create Science" which presents the BRiCS initiative.

We acknowledge seed funding from IIT Kanpur and from Media Lab Asia for enabling the BRiCS activity. Ideas and initial help for the project came from Manu Prakash, Vibhanshu Abhishek, Manish Maheswari, Nikhil Sinha, Gaurav Sharma, Mitch Resnick, Geetha Narayanan, Sanjay Dhande and many others from IIT Kanpur and the schools we have worked with. But of course our best champions are our students, and the burgeoning BRiCSter fraternity worldwide.

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