Designing for Children
- With focus on 'Play + Learn'

Open design for enabling better access to STEM education for children

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Abstract: India's K12 education curricula mandates science laboratories in schools for STEM topics at classes 11 and 12. But most less-funded schools do not have access to experiment kits and do not have permanent laboratory facilities. 'Open design' approach proposes the sharing of designs, knowledge, and information required to build an experiment kit by anyone and teach using them. These bridges the gaps of accessibility and affordance of the experiment kits for the less-funded schools by focusing on enabling anyone to build and use designs.

***Key words: Open Design*, *STEM education for schools*, *Design for children*.**

1. Introduction

India's K12 education curricula mandates science laboratories in schools offering Physics, Chemistry and Biology subjects at classes 11 and 12, to impart students with practical knowledge in Science. Students are assessed on their knowledge in performing the science experiments in their end-term exams. For different education boards such as CBSE, ICSE and State schools, there are syllabi prescribing a list of experiments that a student must conduct and the school laboratories must be equipped with the laboratory set-up and equipment required for those. These experiment kits are supplied by private companies, but their designs are more or less the same. Well-funded schools can afford to equip with several kits for one experiment topic, which gives a better device-to-student ratio. But, most rural and less- funded schools, cannot afford purchasing all of the experiment kits recommended, and they own only a select few kits and only one each for a topic. Need for more space, supplies, and lack of laboratory staff, are some of the other bottle-necks apart from cost for these schools. In order to tackle this issue, the authors propose 'open design' of the experiment kits required for science education in India.

Open design

Open source has been a popular approach in information technology. Open source refers to free accessibility of the code or the information for anyone to use freely. Open access is another method used in academia for free access to contents from publishers. The trend to share knowledge has been led by the software revolution. But its impacts to those deprived to bring about a change is not well noticed to measure its reach.

For example, Google's open source project Android's goal is to avoid one industry player restricting or controlling innovations of other player (Android OS Project, 2019). Android's source code with documentation is available to everyone. Though it is publicly available, one would still need access to good computing devices and have operational knowledge of the programming using the source code, i.e., software engineers, programmers, product and software firms. This limits the usefulness of an open source project, as the number of people and firms who can directly utilize it would be very few in number. The rest are those who benefit from it indirectly, when a product/application made out of it reaches them. This is the limitation of Open source philosophy of information sharing.

'Open design' proposed here is about sharing of designs, knowledge, and information required to build an experiment kit (or product) by anyone and teach using them. This bridges the gap of open-source philosophy where there is barrier of knowledge. Open design enables any literate individual to build it. Through 'open design' less-funded urban/rural schools can be benefitted. It enables them to build and own experiment kits instead of having to purchase them. The focus of the 'open design' approach is on enabling anyone to build and use designs.

To enable anyone to have access to designs and build, *open design* is proposed at three levels — *design, building, and teaching*. In the first level, new designs are created for teaching science topics for which laboratory experiments do not exist at present, or are otherwise costly. The designs are developed in such a way that they cost less to build; the material required are affordable, and easily accessible from either a departmental store or a hardware store; and its manufacturing would involve reasonably ubiquitous facilities such as Laser Routing and 3D printing. These two facilities are accessible to most Indian schools through the Atal Tinkering Labs across the country. The designs can be disassembled and stored, saving space while not in use. For the second level -'*building*'- *open design* is achieved through free access to design documents and the information required for building them to any teacher or student who has access to internet. The information and design documents would involve material and quantities to be purchased, CAM ready files, assembly instructions, and DIY videos. The third level involves, content for teaching the science concept using these experiment kits. Videos on how to operate and use the equipment are provided.

Thirteen experiments from CBSE Physics syllabi for class 11 and 12 were designed using the open design principles explained above. These were tested for its buildability by school teachers using the designs shared to them. Feedback from students and teachers were taken. The results show promise, and the benefits open design can achieve for STEM education in India.

2. Three levels of Open Design

The three levels of Open Design approach used in designing experiment kits are explained here through two of the 13 designs for experiment kits for teaching Physics concepts, developed at the authors' lab.

2.1 Design

The Physics concepts were chosen based on the design team's interests as well as through careful consideration of the value a physical experiment adds to teach that concept. The design started with surveying whether an experiment kit existed in the topic chosen, and if it exists what its limitations are, viz, 1) in teaching the topic, 2) cost of the experiment, 3) space occupied by the kit, 4) interaction with the student (if one-to-one use or not).

Designers were given constraints that the material involved must be accessible and affordable such that one should be able to locally procure from a small-town household hardware store, departmental store, or a fancy store (fashion accessories store), which are pervasive. Manufacturing constraint was that the designs must be manufacturable using Laser routers, and if a case arises for a special part, then use of 3d printing could be used. These manufacturing facilities are accessible through 5441 Atal Tinkering Labs (ATLs) established through the Atal Innovation Mission with its presence in every state and Union territory of India except the Lakshadweep Islands (AIM, 2019) . It connects 6,046,146 Students and the remote Andaman Nicobar Islands too have 23 ATLs (AIM, 2019).

The third constraint was to have space-effective and disassemblable designs to cater to the space constraints in schools without permanent laboratory spaces. Therefore, the conceptualization of the experiment designs, went hand-in-hand with material selection and feasibility check of these constraints.

The concepts selected which meets the material and manufacturing constraints were evaluated for how well the design can teach the Physics concept chosen, and the interaction level of the student with the experiment kit. Higher level of interaction with the student-user was preferred in order to provide more learning opportunities from the experiment kit. The experiments designed therefore had scope for 'experimentation' by the user and were not a demonstration alone.

Figure 1 below shows one such design of an experiment kit to teach the Physics concept of calculating the *Coefficient of Friction*. The design of this experiment has an operable inclined plane with an inbuilt protractor to measure the angle of the plane; and a cube with different surface textures. To perform the experiment, one must place the cube on the plane, lift it slowly and note the angle at which the cube starts to glide on the surface. The material used for this design are MDF sheets, sandpaper, thread, metal shaft, and manufacturing involved is laser cutting.

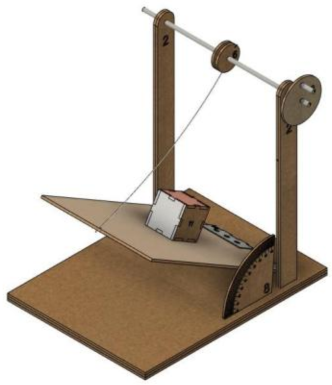


Figure.1 Design for the Coefficient of Friction Experiment

2.2 Building

The second level in open design – '*Building*'- enables one to build the experiment kit through free access to the necessary design information to anyone - a teacher, student or anyone who has access to internet. The information is made accessible through a web portal to the schools. The '*Building*' information document includes the *bill of quantities* with information on where to purchase them;CAM ready files for laser routing; assembly instructions sheet; and DIY help videos. Table 1 below shows the Bill of Quantities for the *Coefficient of Friction* experiment kit. Once the material is procured, the '*Building*' document directs the material and the CAM ready file to be used for the manufacturing step. Figure 2 shows the CAM ready file for laser routing of *Coefficient of Friction* experiment parts.

The last step in '*Building*' is to assemble the parts, and the assembly instruction sheet gives step-by-step instructions to assemble the kit. Figure 3 shows example assembly steps of *Coefficient of Friction* experiment. Video instructions for assembly are also made available if the assembly steps are more complex for certain design of experiment kits (See Figure 4).

Sl. No.	Material	Quantities	Store
1	MDF Board of 1000 x 600 mm	1	Hardware Store
2	Shaft of Dia. 6 mm & length 300 mm)	1	Electronics Store
3	Shaft of Dia. 6 mm & length 50 mm)	1	Electronics Store
4	Door Hinge	1	Hardware Store
5	Sand Paper (4 different grits)	1	Fancy Store
6	Thread	1	Fancy Store
7	Glue (743 Glue)	1	Hardware Store

Table 1. Bill of Quantities for the Coefficient of Friction Experiment

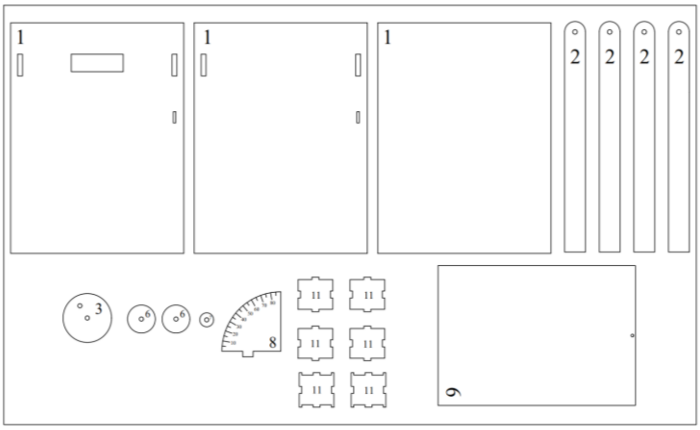


Figure.2 CAM Ready File for Laser Routing

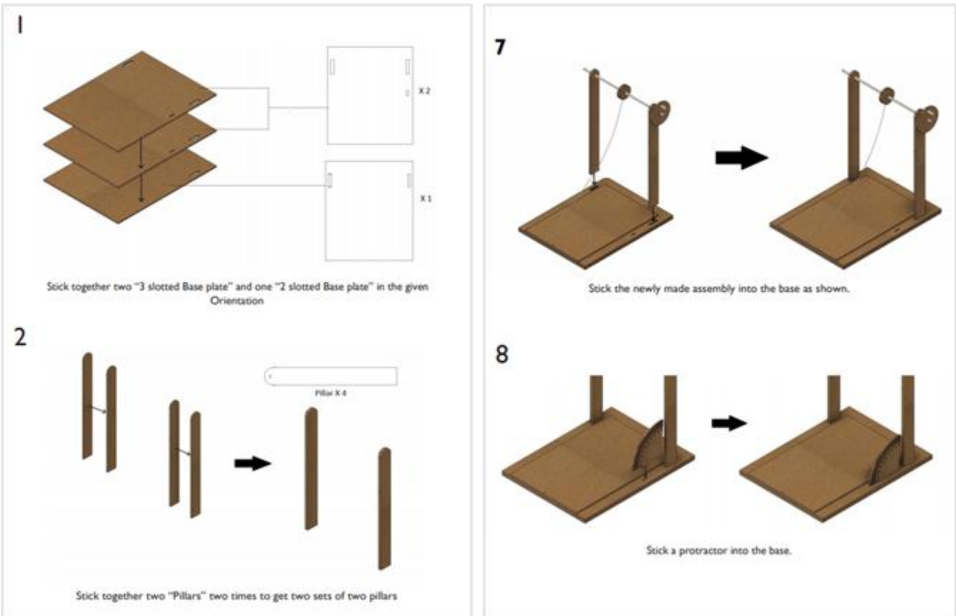


Figure.3 Assembly Instructions Sheet

2.3 Teaching

To aid teachers in teaching students using the new experiment kits designed, videos contents on how to perform the experiment, along with inferences one could draw from the experiment cases, are shared. Teachers can teach using them or students themselves can watch the videos and perform the experiment themselves.

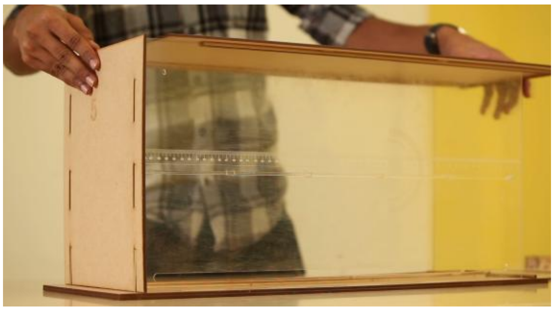


Figure.4 Video Assembly Instructions for an experiment kit to teach Ray Optics.

3. Validating Open Design approach with schools

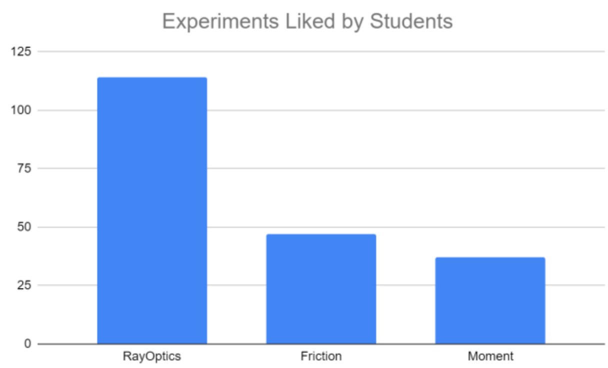
Three less funded state schools in Bangalore urban region were first approached for the validation. All schools refused to participate. The reasons cited were school schedule; lack of interest by teachers to spend additional work with new experiments; and schools own those experiment kits that would be most likely tested in the final practical laboratory examinations of students.

Figure.5 *Coefficient of Friction* (left) and *Ray Optics* (right) experiment kits before assembly.

The fourth school approached was a state government owned Pre-University College in Bangalore rural region and its teachers expressed immediate interest in participation. As the school had very few teachers to monitor the students, and to encourage participation by reducing the time for testing, the material was procured and machined and provided to them. Two teachers (one teaching Physics and one teaching Chemistry) were given the parts, the assembly instruction sheets for three different experiment kits - *Coefficient of Friction, Ray Optics, Moment*. Figure 5 shows two of the experiment kits built by the teachers. They were given one-hour time for each experiment to build it. There was an initial reluctance to do the hands-on activity alone, and after a while both teachers decided to do it together where they discussed among each other while assembling the model. The teachers were able to follow the steps and assemble the kit themselves.

Once the kits were assembled, the teachers called the students and taught them *Ray Optics* and *Coefficient of Friction* experiments using the kits. An informal feedback was taken from students. All students were excited to use the Ray Optics kit where the concept was otherwise hard to visualise. The same three experiments were later taught to 172 students of K8-K12, and the students were asked for feedback on which experiments they liked and comments for the same. The results of the survey are shown in Figure 7. The experiments were later taken to a private funded school and two Kendriya Vidyalaya schools in Bangalore where the learning by students were measured. A part of this work is reported elsewhere by the authors (Moothedath Chandran et al. 2019).

Figure.6 Teacher explaining concept of *Ray Optics* using the kit they built.



Comments
The path of the laser, later converging through the lens was cool !
Nice ideas, could be used to explain school definitely
It was very Practical
Good, easily understandable
Wonderful and interesting to learn
Nice Experience,Easy way of learning
Creative
Absolutely Practical,Very Interesting And clear

Figure.7 Survey on students of high school. Comments given by students on right.

4. Discussions

Among the three levels of Open Design – *Design, Building, Teaching* - the key learnings from this study for its level 1- *Design are* : the system level issues at school education concerning less funding, lack of teachers, school hierarchy structures, etc. are indeed the key barriers as expected. Hence it is very important to consider these aspects at the design level such that the designs can be built by 'anyone' using the information shared, not necessarily by teachers. In the present validation, the teachers built the designs.

The level 2 of open design- *Building* - is where the interaction with the builder of the kit and its reach to the students takes place. The key challenges are – though the kits are cheap to build, teachers need to spend from personal funds to pay for the purchase of material; teacher's availability of time to spend in building the kit; access to internet for design information; and access to the nearest ATL. From the study at the schools, access to internet was not an issue due to mobile internet availability, and the teachers were presently spending their own money for lab supplies for their students. The teachers reported they would be willing to spend from their own funds if the resources required for the kit are affordable. As not all teachers and schools are motivated to build kits, through Open Design, the approach enables anyone to take the initiative to build and provide an experiment kit to a school. The person could be a student, a parent, a volunteer, or through Atal Tinkering Lab staff.

The last level 3- *Teaching*, was the least challenging, as the teachers found it easy to teach the Physics concept with a physical experiment, and students were able to experiment and observe with the kit. If teachers are not available, anyone could teach using the videos shared online.

Primary	Upper Primary	Secondary	Senior Secondary
4.13	4.03	17.06	3.34

Table 2. Average Annual Drop-Out Rate in School Education: 2014-15 (In percentage). Data Source: National Institute of Educational Planning & Administration, New Delhi. (MHRD, 2018).

From this study, the Open-design approach is found very relevant to the Indian context. The schools approached were less funded with as low as Rs. 2000/- per year as annual funds sanctioned for its expenses including laboratory maintenance. Two out of the three government schools did not have a dedicated space for laboratories. They had make-shift arrangement for Physics lab, labs were used as storage rooms.

As the highest student drop-out rates in India are at secondary level schooling (See Table 2), it is important to look at the reasons behind this. The Gross Enrolment Rate (GER) is only 56.2 at higher secondary level (GER denotes the rate of enrollment from corresponding age group in the population) (MHRD, 2018). This means the remaining half of the population do not make it higher secondary level education. The top reasons for drop-out for male students and the second top reason for female students are cited as *'Child not interested in studies'*. *'Únable to cop with studies'* is one of the top 5 reasons for drop-out for both male and female students (MHRD, 2018). To address these reasons, experimental and activity-based learning of STEM topics would improve students' interest and understanding of complex concepts at secondary and senior secondary school levels. By enabling the reach of STEM experiment kits to many remote and less funded schools, it would be a step towards supporting learning STEM topics through performing experiments.

6. Conclusions

India must address the needs of quality STEM education for its large population of students. With its 15,22,346 recognised schools, and unrecognized schools (figure not found), a radical intervention is required to break the barriers of affordance and accessibility for enabling better STEM education. Several NGOs try to reach remote villages with mobile learning kits. Private companies sell mobile-based learning Apps, but these mostly target the students from better economic background. These methods only bridge the gap of reach of teachers/teaching to students. The Open Design approach addresses the root cause barriers of accessibility and affordance, by interventions starting at the design stage itself that change the way experiments kits are designed, and by enabling anyone to build and teach using the kits.

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