THRIFTY MAKERSPACES PROJECT - YEAR 1 IMPLEMENTATION REPORT

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INTRODUCTION

Educational makerspaces are collaborative learning spaces where the participants explore, create, learn, and share as a community, while building things that are meaningful to them. In the process of making and exploring, the students develop skills that are difficult to obtain in a traditional educational setting, while also affecting and unraveling their identities. Thus, an educational makerspace is far more than just the space itself; it is also about a mindset that needs to be cultivated among learners, especially the young people the makerspace serves (Gerstein, 2014).

While makerspaces started as hobby spaces for adults, today, educational makerspaces have a prominent role in the current schooling landscape, particularly in developed countries. Maker education is bringing hands-on exploratory learning to schools, where it encourages a project-based, experiential approach towards learning. Moving further from their early days, makerspaces today are increasingly seen by educators as integral to jumpstarting lifelong interest in STEM fields among students (Peppler et al. 2015). While some may still see the open-ended exploration and seeming lack of elaborate planning and directions in a student's work during tinkering as problematic and unsuitable for their readiness for the STEM careers in the future, in reality, expert practitioners in STEM fields employ much more tinkering than what is common in STEM classroom activities (Brown, Collins, & Duguid, 1989). Thus, tinkering in a makerspace is one of the few things that a school can provide where the students may directly develop key skills for the future, such as creativity, critical thinking, and collaboration.

Although the birth of makerspaces and the recent spread of the maker movement as we know it today are primarily attributed to the West, the traditions of tinkering and maker mindsets exist in cultures all around the world. In many countries, the do-it-yourself attitude may have evolved out of necessity, whereby people made best use of whatever tools and materials were available to them (Resnick & Rosenbaum, 2013). For example, in India, where the implementation of this study is based, the culture of making and tinkering runs deep in society. There is even a vernacular term, "jugaad," that roughly translates as "an innovative and low-cost hack to solve any problem." Humans are born tinkerers, with a natural affinity for exploration and discovery, and the innovations that tinkering drives have been one of the greatest equalizers across all societies in history.

However, the current maker movement in education is failing to achieve its promise of equality at a global scale. In most developing countries, makerspace implementation happens via a copy-paste model from the West, which often leads to presumptions that to conduct maker-based learning effectively, educational makerspaces need to have expensive tools and materials such as 3D-printers, laser cutters, or CNC machines. That presumption is not only false, it is also detrimental to the spread of the maker movement, preventing it from reaching the parts of the world that can't afford such equipment and are most in need of a transformation in their teaching and learning practices. Especially when implemented with an equity lens that leverages the intellectual, emotional, and cultural resources that students bring to the makerspace, maker learning has immense potential to engage the underprivileged and underrepresented (Vossoughi, Escude, Kong, & Hooper, 2013). Unfortunately, in developing countries, such schools also tend to fall into the trap of valuing expensive equipment and materials far higher than the socio-cultural aspects of the makerspace community, aspects which possibly play a bigger role in ensuring whether a makerspace is sustainable or not in such contexts.

This project therefore challenges the assumption of critical dependency on expensive resources and investigates a systematic approach for building sustainable makerspaces in resource-constrained environments. Rather than considering the lack of resources a constraint to maker-based learning, we see it as a catalyst for frugal innovation (Prahlad & Mashelkar, 2010) that can help inform and facilitate the spread of the maker movement to parts of the world that have yet to benefit from it. The goal of the first year of project implementation was to develop a prototype model of an educational makerspace built from scratch in a resource-constrained school and build an understanding of various aspects of its development process. Key expected outcomes for the participating students were an increase in their learner agency and productive risk taking.

In India, there has been a push for building educational makerspaces in schools, given the recent government program intended to open makerspaces in 2,000 schools across the country from 2017 to 2020 (NITI Aayog Annual Report, 2017). However, the implementations of these makerspaces are based on highly prescriptive rules and regulations (Gadre, 2018). There is a severe lack of systematic understanding of what it takes to build a makerspace from scratch in such a way that allows it to continue beyond the initial push by the outsiders. Indian schools are particularly prone to rote learning and other outmoded educational practices, and efforts to incorporate innovative forms of learning have thus far been limited to expensive private schools (Misra, 2016), thus perpetuating and intensifying existing inequalities in Indian society. Maker education holds immense potential to bring a positive transformation to the Indian school system and better prepare students for the 21st century, and it therefore becomes imperative that we develop a deeper understanding of the various factors that underlie a successful implementation of maker-based education in Indian schools.

Design Principles of the Model

Informed by existing research on makerspaces for learning (Sheridan et. al, 2014), our model of development follows an iterative design process, developing the following three interconnected elements of building makerspaces:

Spaces

Educational researchers who examined the design of makerspaces have identified common characteristics that are conducive to design, making, and learning (Litts, 2015). Based on their work, this project builds makerspaces that offer students an unstructured drop-in space where they can hang out—a “third space” that the students see as between their school and home, where they can work informally, and that provides them with meaningful engagement and a sense of belonging (Oldenburg, 1989). The environment of a successful educational makerspace is intentionally designed to inspire wonder among the students, incite their curiosity, encourage playfulness, and celebrate unique solutions (Kurti et. al., 2014). Several small enhancements to makerspaces, such as having display walls for showcasing past projects, will be utilized in our makerspace designs to help students draw inspiration and generate new ideas.

Materials and Projects

As a makerspace is established, the list of equipment and materials should naturally grow as specific projects and programs generate new ideas (Britton, 2012). However, schools commonly approach the establishment of makerspaces by acquiring a certain set of equipment and tools, such as 3D printers, laser cutters, and CNC machines, without considering the needs specific to the school. With this approach, the startup costs can easily add up to $15,000 or more (MakerEd, 2014). Our model utilizes the local context of the students and attempts to make tools and materials as relatable to them as possible. Students are also encouraged to come up with creative ideas and to work on projects that focus on problems that are meaningful and important to their lives. These project ideas drive what materials are procured for the makerspace.

Community Building Strategies

To support community building in the makerspace, various approaches for initial capacity building and learning of the members must be employed. First, the model utilizes the effective learning strategies discovered from the "studio structure of learning" where more experienced makers lead demonstration-lectures, show exemplars, and demonstrate processes (Hetland, 2007). Second, the model introduces norms and values for a productive community of practice where learning is part of ongoing social interaction. In addition to the benefits of shared knowledge and experiences, developing this community of practice also promotes a sense of identity among students as a member of their maker community (Wenger, 1999). While cultural inertia and specific social contexts may make any such transformation a difficult process, effective implementation of the community building strategies is of paramount importance for systemic change to occur.

Implementation

The implementation of the makerspace program was conducted in a government school in Bangalore, India. India was chosen as the problem statement of the project is deeply reflected in the education system of the country, especially in low-end government schools at all grade levels, where the teaching approaches remains both highly traditional and ineffective. Typically, a teacher tends to play the role of a know-it-all, sage-on-the-stage, while the students remain the least important part of the equation with no agency over their own learning.

School Description

The project was conducted in a government school in Bangalore, located on the outer part of the city, near a central jail in an underdeveloped location. The crime rate in the area is relatively high, including occasional break-ins at the school where materials and equipment would get stolen or damaged. Identifying an appropriate site in the school, considering the needs for the security of the makerspace, was particularly difficult during the early days of the project. The teachers also reported a few cases of drug abuse among the student community at the school.

Figure 1: School building

The school building resembled that of a typical government school in India, with a central courtyard surrounded by two or three storied buildings. The classrooms in the school tended to be dark and crowded. Each class had about 75-85 students in it, with the role of the teacher mostly revolving around disciplining the students and keeping the chaos in the classroom in check, even when that came at the cost of academic engagement and learning efficacy among the students.

Figure 2: School courtyard

The students severely lacked understanding of even the basic concepts expected at their grade level. For example, despite being in the ninth grade, the students could not explain simple things such as the area of a square, what resistance in an electric circuit means, or even what are electrons. However, the same students seemed quite sharp, creative, and resourceful when it came to the aspects of learning that were not directly part of their curriculum. This was indicated through many conversations that the project facilitator had with the students around what kind of problems they typically encounter, what they could do to fix them, or even in conversations about their general interests. The classroom instruction and assessments severely emphasized rote learning over understanding at the school. Although there were one or two teachers at the school who saw this as a major problem and wanted to do better for their students, the support and resources for such teachers was almost non-existent.

Selection Process and Criteria

The selection process for the school site took about six weeks, wherein the project team visited multiple school sites across the city, met with principals and school administrators, teachers, and students. The school selection involved five major criteria: location, infrastructure and resources, administrative buy-in, school's value alignment, and students' interest.

Location

The location of the school was important, to ensure the project was implemented in a location where the target population resided. Bangalore, like most Indian cities, is economically diverse and stratified, where some pockets tend to have a concentration of rich and well-to-do populations with high-end schools, while other areas are extremely poor with only government schools or low-budget private schools. Placing the project in an appropriate neighborhood was important to the success of the project. Another factor in choosing the location was its general accessibility, given that traffic in the city is a major challenge, and traveling even relatively short distances can take hours during peak times; anything too distant would have led to significant difficulties in its everyday reach for the team. However, the project team didn't want the prototype location to be in a remote, rural area, either, where even materials would have to be sourced from places that were outside the purview of the students. Although that ruled out a large majority of resource-constrained schools in the country, only a few relevant sites were needed during this phase the project. Therefore, for this particular project student access to small hardware stores or mechanics was prioritized when selecting , as it was important to study the students' engagement and sense of ownership in the makerspace.

Infrastructure and Resources

Given the problem statement focused on resource-constrained schools, the site selection process involved deliberately identifying schools that severely lacked resources and had poor infrastructure. While the school site chosen for the project had a large school building, the overcrowding in both the classrooms and the school made the available space look grossly insufficient. The school suffered from frequent power cuts, leading to students learning in poorly lit classrooms, and lacked consistent access to many other basic amenities. Also, unlike most other schools in Bangalore, the chosen school was not involved in any corporate social responsibility (CSR) projects, which ensured that the students engaging with the project were only part of one active research intervention at a time, thereby helping make valid observations about the impact of the project. As one precondition, the project required that the school have some space where a makerspace could be set up, which in this school was a challenge given the severe lack of any spare space, so it was crucial to think outside the box with regards to placement of the makerspace at the school.

Figure 3: Students during lunch break

Administrative Support

While we did not expect every teacher to understand the value of a makerspace and learning through making, securing buy-in from certain key people in the school was important. The project required that at least the school principal and a few teachers who would be directly impacted by students' involvement in the makerspace be onboard and supportive of the idea. In the selected school, the Biology teacher became the biggest champion of the makerspace, convincing even some of the other teachers in the school of the importance of hands-on learning for their students. The principal of the school was also highly supportive of the idea. Unfortunately for the project, however, this principal was transferred to a different school soon after the project started, though since no one as yet has been hired to replace her, the project did not run into the challenge of convincing someone new who may not have necessarily seen the value of having a makerspace in the school.

In general, teachers in the government schools of India have little incentive to take on any extra burden, so external projects like this typically struggle to find support. India has no comprehensive set of education standards that a teacher may have to meet, so a makerspace possibly helping them with their teaching by satisfying some pre-identified learning standards as such is also not an incentive. Overall, the process of getting buy-in among teachers came down to identifying individuals who truly understood what the project was trying to achieve and agreed with it.

Value Alignment

The school administration's values around students' learning and agency were taken into consideration as one of the key requirements in the site selection process. This typically involved having conversations with the school principal and certain teachers for subjects such as science, math and arts. Attempts were made to make them understand the importance of learning through making and of the tinkering mindset for a child. While in some schools, such discussions were not well-received, the principal and the teachers at the selected school site welcomed the idea and readily agreed to conduct this project as an experiment in their school. While it can't be said with certainty, having a school leader who was especially encouraging to teachers, and who made extra efforts to make learning for their students more meaningful, definitely had a positive contribution towards these teachers understanding the importance of makerspaces, beyond their own personal passion for seeing education done well. Some of the teachers at the school had also attended some teacher trainings on hands-on science learning with the Agastya Foundation, a local partner organization for this project, which may have also helped shape and inform the thinking of these teachers. Meeting these teachers and the principal at this school was particularly encouraging and refreshing, as in most Indian government schools the teaching remains extremely passive, with little to no importance given to student voice and choice, or to practically engaging them with their learning process in any way.

Student Interest

It is important to have a sense of students' interest in the project as a criterion, because while we would like to believe that given enough time any set of students should be able to get excited about the idea of hands-on learning, when students have been through a specific kind of learning experience for more than a decade, those methods can come to be seen as familiar and even preferred. This implies that in certain cases, even the students that one intends to target may not show much enthusiasm for setting and running a makerspace. This was not easy to judge, since a few attempts at using questionnaires for understanding students' attitudes fell flat, owing to students treating them as a test despite multiple efforts at clarifying how those questions didn't relate to their school marks in any way possible. Eventually, informal discussions with small groups of students were employed to get an understanding of students' interests and motivations for participating in a project like this. Given that the project engaged with relatively senior students in the ninth grade, many of the students at the selected school site had mostly given up on their studies, however, as a strongly shared sentiment they all seemed extremely excited at the idea of working on this project.

Makerspace Description

Setup Phase

In order to set up the makerspace in the school, an appropriate site had to be located. There were three key points that were important to meet:

1. the space needed to be accessible to the students but did not have too many distractions, especially in terms of the frequent intervention and oversight by the school authorities;
2. had enough room for at least 15 students to work at a given time, and did so despite the severe shortage of learning space at the school; and
3. gave the students a strong sense of ownership, building in them the feeling that they belong in the makerspace and the things in the makerspace belong to them.

Figure 4: Starting condition of the site

The project was introduced to the ninth grade students by their science teacher, and interested students were asked to chat with the project researcher at the school. After addressing students' queries and detailing further to them what the project entails, a group of eight enthusiastic students formed the initial set of early participants. The first step in the setup involved identifying a location, which, after debating all options with everyone, was chosen to be an underutilized junkyard towards the end of the first floor of the school near the eighth and ninth grade classrooms.

Figure 5: Broken furniture and other discarded school junk piled at the site

The junkyard was mainly filled with old and broken discarded furniture which students helped condense into a pile in one half of the space, thereby freeing the rest for the makerspace. A partition was created between the two halves using tarpaulin sheets. The space was also open from all sides except one, with just an iron grate covering it on the other three sides, so tarpaulin sheets were also used to cover the iron grate on an additional side, giving it the space semblance of a room with a large window on one side. While this choice of location for setting up the makerspace meant a lot of work for everyone involved, it provided a workspace large enough for the expected number of students, without putting any additional pressure on an already space-constrained school. The regular involvement of the students from the beginning in all set up activities from planning and decision making to execution instilled in them a natural sense of ownership for the makerspace. They even gave it a name, "Namma Makerspace," where "namma" translates to "our" in their native language Kannada, and proudly wrote it on a board to display at the entrance for others in the school to see.

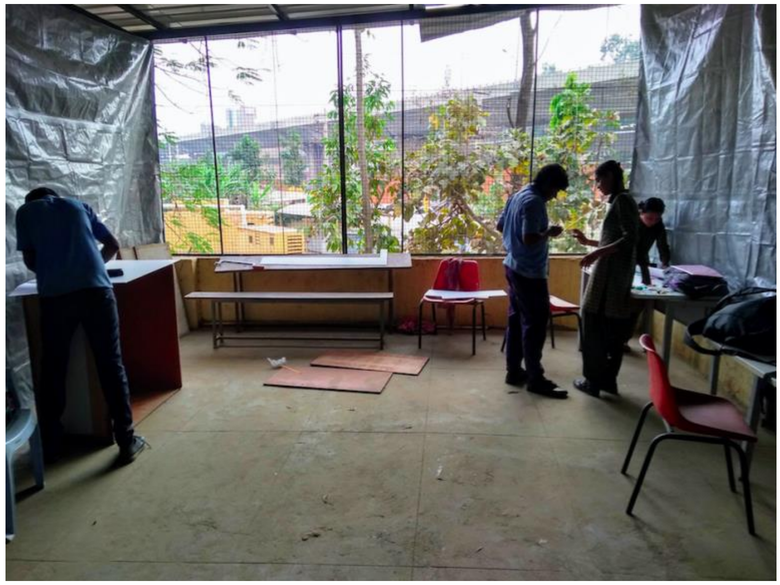

Figure 7: Covering the makerspace on two sides with the tarpaulin sheets

Figure 6: Students naming their makerspace

Structure

The makerspace was a moderately sized rectangular space with plenty of free space for the students to move around. The woodworking materials were towards the end of the space near the open area, so that noise and wood dust could be kept limited to a corner. Since there was only one power plug near the entrance to begin with, most of the electrical work tended to happen there. Materials were stored in plastic boxes and were kept in a designated area with the respective labels for their categories. While there were several smaller tables along the sides that formed different work stations, there was a large table in the center of the makerspace. This big table was where most of the collaborative worked happened.

On a regular day, the students would come to the makerspace between 3:00-4:30 pm during school hours. This would be the time when they would have free prep, which their acting principal suggested would be the ideal time for students to work in the makerspace. The school authorities decided against opening the makerspace when the project researcher wasn't around, so the researcher's presence was always required for students to access the makerspace. Initially, the researcher had given the makerspace keys to one of the responsible students, but after the door was left unlocked by the student, the school authorities decided that the school administration and project researcher should be the only ones with access to the keys.

Figure 8: Makerspace after initial setup

The materials used in the makerspace were procured from nearby shops. There was a small market in walking distance of the school with small hardware and office supply shops could be found. Given that most students lived close to the school, they generally did their shopping at this market. A deliberate attempt was made to purchase materials from that market, and in smaller amounts, mostly just enough for the requirement. The students were typically not allowed off campus, but sometimes teachers allowed a few of them to accompany the project researcher while going out to buy project supplies. Given the local nature of these supplies, their costs were quite low, and were also paid for by the project. While typically buying materials in bulk for a makerspace is more convenient and makes more economic sense, buying things in small amounts only as needed was important, as this approach closely resembled the consumption patterns of students and their families and kept the makerspace experience relatable. The idea was to avoid actions that these students would not be able to replicate if the project researcher was taken out of the equation.

Values

The makerspace had a mix of explicit and implicit values that were gradually set in place. Some of these were directly told to the students in the beginning as they showed interest in the project, but many were established overtime via opportunities that emerged through different day-to-day scenarios at the makerspace. Yet rather than writing these values down somewhere, as a facilitation strategy it was preferred that they be established in a more natural fashion with the students through various daily activities and emerging events at the makerspace. Partly, this choice was in reaction to the students' severe lack of agency in school: they were too used to doing what they were told, a pattern which would have repeated if we directly told them all of the makerspace values as a set of rules.

One of the key explicit values was that the makerspace should be welcoming for everyone. The students who were part of the makerspace from day one especially felt a bit territorial about the space, so it took several casual conversations for them to realize that the purpose of the makerspace could not be achieved if we made it exclusionary in any regards. Special attention in this direction was placed on ensuring that the girls in the makerspace felt particularly comfortable. In India, the stereotypes around gender roles run deep. Even in this school, girls tended to assume that engineering and science activities were only for the male students, whereby girls were typically seen sitting in groups stitching or doing other artwork but never anything related to STEM activities. Breaking these stereotypes was important, and it took deliberate efforts to ensure that the female students felt comfortable in the makerspace, including some active regulation by the researcher of any exclusionary language, including in the casual remarks and comments that the students made.

Figure 9: Students building tables for their makerspace

Another important value was that the students supported each other with their projects. To inculcate it, the researcher would try to redirect a query or request from any student to another student who was best capable of answering it rather that addressing it himself. Over time this became a natural habit among the students, where they would directly look for help or specific advice from their peers. This formed a culture of joint ownership of the various projects that were being built, rather than each student merely focusing on their own project.

Figure 10: Students building a cupboard for their makerspace

The students who formed the makerspace also brought many helpful values with them. Chief among them were resourcefulness and a thrifty lack of wastefulness. Given the backgrounds of these students, items at their homes are typically not discarded unless there is absolutely no use or reuse for them, and they brought the same approach to materials in the makerspace as well. There would be many times when various tools like soldering irons or hot glue guns would burn out, and in no time, a student would have taken it apart and put it back together in working condition. Since the makerspace was only a tarpaulin partition apart from the school junkyard, the junkyard itself became a giant pool of raw materials for different things needed in the makerspace. For example, none of the furniture in the makerspace was brought from outside, but rather was all built from the broken furniture in the junkyard, fixed and repurposed to suit the needs of the makerspace.

Student Description

Since the chosen school was a government school, the students there primarily came from low socio-economic backgrounds. India as a country has a rapidly growing economy, where, increasingly, more households from the lowest economic strata are moving higher into an aspirational burgeoning middle class. The majority of the students' families belonged to the economic lower-middle class, where one barely has the means to meet their most essential needs. Some of the students in the makerspace would assist their parents at their work after school, be it at a tea stall or in a carpentry workshop.

Academic standards at most government schools in India are low and this school was no exception. The students in the makerspace, despite being in the ninth grade and including some of the high scorers of the class, lacked even the most basic understanding of the topics in their curriculum. However, what made them excellent makers was a strong sense of hope, despite full awareness of what all they lacked, be it academically or economically. They had a strong desire to learn and the street smarts to make things work.

Figure 11: Students building a storage box with LED eyes

Facilitation Strategies

An important factor in making a makerspace like this potentially sustainable is minimizing the presence of the external facilitator as much as possible. These students are used to following instructions when in school, so if the facilitator does not make active efforts to make themselves redundant in the space, then students will look to the facilitator for directions. In general, this involves the facilitator not intervening unless absolutely necessary. At times, students will make mistakes or take approaches that make the process painfully long, but in such cases the facilitator needs to hold back the urge to intervene and let the students figure things out. That being said, there are times when an indirect nudge can make the whole thing a significantly better learning experience for the student, in which case one should go ahead while exercising their best judgement while still keeping in mind the larger principle of minimal intervention.

The students, more so in the early stages, want to be told the answers to everything, mostly how to make something work. As a facilitator, one should take a Socratic approach to answering such questions and engage in low-stakes active questioning that makes the students themselves arrive at the correct conclusion. Overall, it is of the utmost importance that the makerspace does not feel prescriptive. The students should feel welcomed and encouraged to drive things. The facilitator should hold back and let the students drive the projects and even the decisions about what materials need to be procured.

MAKER WORKSHOPS

Besides the regular activities at the makerspace, where the students would work on their various projects, students were also provided with an opportunity to directly learn from and be inspired by maker experts via two maker workshops conducted over the course of the year. The purpose of these workshops was to give a boost to the excitement of the students and teachers around tinkering and making and have these exemplars to build a deeper understanding in them of what these values look like in practice.

WORKSHOP WITH THE LOCAL EXPERT

Figure 12: Students playing with magnets and bolts

The first workshop was conducted around the mid-point of the project intervention by a professor from the electronics and communications engineering department of a technical university in New Delhi. The professor directs two open access laboratories, one of which, the Centre for Electronics Design and Technology (CEDT), works like a makerspace for university students though primarily focused on electronics projects. In addition, he advises schools across India that have implemented makerspaces and conducts workshops with the students there. At the Namma makerspace, this workshop was a day-long event with students from eighth and ninth grade along with several teachers at the school. The first half of the workshop was more demonstrative, where several exciting projects were shared with the participants, along with the motivations, concepts, and techniques involved in their making, while in the second half, the students got to engage in hands-on building some of those projects themselves.

WORKSHOP WITH THE MIT TEAM

Towards the end of the school year, a week-long workshop was organized at the makerspace where a team of maker experts from the Edgerton Center and the Playful Journey Lab at the Massachusetts Institute of Technology tried to engage students in certain maker activities and also learn from what the students had been working on thus far. The idea was to further excite the students about learning through making and helping them see the connections between things that they may have learned in the classroom and what they see in the real world.

The workshop began with the Boston team spending a day getting to know the students and building an understanding of the different projects that the students were already making. The team learned about projects such as solar houses or a vacuum cleaner that some girls were making with a water bottle, and simultaneously some new ideas for projects, such as a lantern using LEDs and Depron sheets, were initiated during these discussions with the students.

Given the limited nature of time during this visit and observing the major gaps in students' knowledge of basic topics, the workshop team on the third day initiated a more directed learning session on the topic of optics with the students. This involved a lot of play with light and various materials such as mirrors, lenses and prisms. The students also took part in making a short project called Aurora Bears, where they assembled a set of pre-fabricated cardboard pieces, along with some colorful LEDs and transparent structures, such that the assembly led them to some fascinating play with light and colors and pushed their curiosities to dabble with puzzling questions around the various effects they could observe. Such play with colorful light built and clarified their understanding of the nature and composition of the light and how we see different colors. The workshop also became an opportunity for the rest of the school to engage with what was happening at the makerspace. The team held some activities outside the makerspace as well, around waves and patterns, where many more students and teachers could engage. While some fascination of the students could be ascribed to the novelty of having the foreigners in their little school (something that is a typical cause of excitement among people in India who are not used to seeing them around), the overall engagement of the students went well beyond this mere novelty factor.

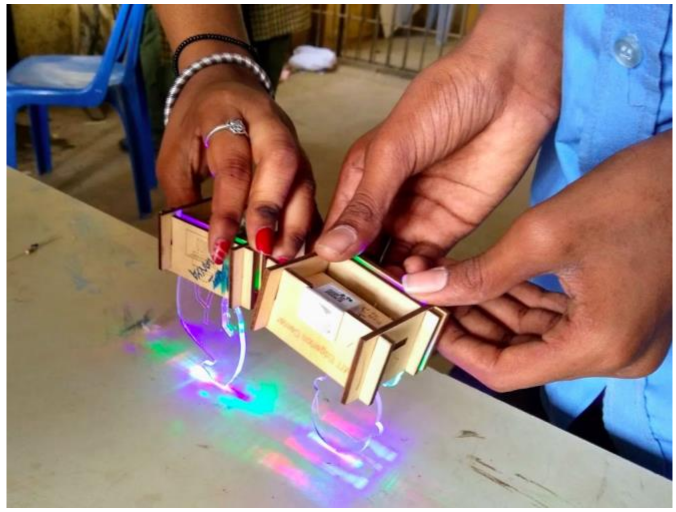

Figure 13: Students displaying their Aurora Bears and its effects

One transformative moment happened during the workshop, when the teacher who was most opposed to the students' engagement at the makerspace in the school, a ninth grade Physics teacher, was invited by the researcher to take a look at what the students had made and let the students take charge of the situation. This teacher believed that the makerspace was a distraction for students, who already lacked discipline and needed to spend much more time learning what is in their textbooks and will thereby be asked in the exams. As a result, during the workshop, where students normally spent the entire day at the makerspace with the permission of their respective subject teachers, the plan was to send the kids back to the class during their Physics period. However, one day the kids forgot to leave on time, and spotted the Physics teacher angrily coming towards the makerspace from a distance. Since the students feared this teacher the most, her

Figure 14: Student takes the lead on explaining his project to the teacher

approaching the space sent a furor among the group, where they warned each other to behave and be prepared to explain. After she was invited in by the researcher, the students went out of their way explaining each of their projects in high detail, displaying their excitement and intelligence, and a sound understanding of the topics they were talking about. While the teacher initially was critical and threw difficult questions back at the students, her cynicism gradually gave way to being genuinely impressed by the students' explanations and their work and enthusiasm. She spent her entire period just talking to the students about their projects at the makerspace, and while leaving, she asked the researcher and the team if they could do something similar with the students in her tenth grade class. This request was particularly surprising, as tenth grade is the year of the high stakes exams that are nationally conducted in India, and the schools don't allow any outside intervention with those students. The workshop team gladly conducted two 1-hour sessions on optics with her tenth grade students as well. Later on, this teacher who had been the most skeptical about kids spending time in the makerspace, became one of the biggest supporters of the project at the school. The transformation of this teacher was not just highly motivating for the students, but also a heartwarming and validating experience for the whole project team.

FINDINGS

SPACE DESIGN FEATURES

REPURPOSABILITY OF SPACE

One of the biggest challenges in setting up a makerspace in the resource-constrained schools of India is the lack of free space. The schools typically are over-crowded, especially government schools and low-budget private schools, which means a continuous struggle with space for the school administration. In such a setting, expecting any school to create the necessary space for a makerspace, whose concept and value proposition are not immediately clear to the administration, is a bit far-fetched. Most other interventions that happen in such schools, whether from some NGOs (non-governmental organizations) or as part of various CSR projects of large companies, tend to follow a fairly top-down approach, meaning the school administration has little choice but to comply with the demands. This is far from ideal, and the moment that high-level push is removed, the project falls by the wayside. If such projects are to become sustainable, it is important that the school administration see the value in project without having to add any significant burden on their resources and infrastructure.

Repurposing an existing space and utilizing it in a more effective way therefore provides the perfect opportunity of setting up the project without needing the school to go out of their way to accommodate it. As described before, in this project an existing junkyard was used by clearing half of it, better arranging all the broken furniture and other discarded items such that a new space was created where previously none existed. This made the school administration far more welcoming of the project, as they did not have to cater to the project's need of space by allocating one of their scarce rooms.

While it is true that there are other approaches of assimilating tinkering and makerspaces into a school without the need of a full room, some of those approaches don't apply well in such schools in India. For example, there are no libraries or labs, which in a different school context might become the host location for the makerspace activities. Transforming a small section of the classroom into the maker corner can also work in certain settings, but not in an over-crowded classroom with almost 80 students. In such classrooms, teachers already struggle to keep the chaos in check, devoting considerable amounts of time to merely maintaining some order; anything that can potentially add to the chaos is a huge “no” from the teachers. Repurposing an underutilized space to build the makerspace addresses the problem wonderfully without making the school administration’s life any more difficult.

Student Involvement in Setup

Involving students from the outset in the setup of the makerspace was one of the best decisions made during this project. No amount of effort invested towards building a sense of ownership among students at a later stage can match what their active involvement in the setup phase can achieve. Many attempts that are made at establishing makerspaces in schools tend to first finish most of the setup of the space, and then invite students to a grand opening. This is makes for a huge missed opportunity, as directly involving students early-on in the design process immensely raises the probability that the outcome will suit the user’s needs. Additionally, it conveys intentionality of every small design decision to the students from day one, thereby reducing the need for any explanations later on.

Besides, having students take part in setting up the makerspace provides a convenient and wonderful experience, as it not only provides more hands to seek help from, but also allows facilitators to get to know the students quite informally. In an Indian context, that becomes quite helpful, as bridging some of the huge gap which exists between learners and teachers in a traditional setting is of the utmost importance if students are to feel comfortable in the space. Initially, the students saw the project researcher as a teacher figure, or even as an unrelatable outsider, but in the process of setting up of the makerspace, they gradually opened up and thereby began to enjoy the whole experience significantly more. This led to a deeper connection and a better understanding between the researcher and the students. Such low-stakes experiences make everyone more comfortable with exhibiting their strengths, as well as exposing their vulnerabilities. Personal understandings at such levels also allow for a smoother resolution to any issues that may arise later as the work in the makerspace continues.

Maintenance and Upkeep

Just as with setup, it is crucial that the students be actively involved in the maintenance and upkeep of the makerspace. They need to take charge of various responsibilities entailed in running the makerspace, which include a range of activities from clean up and maintaining other students’ access to the makerspace, to keeping track of all the inventory and even liaising with school authorities when applicable. When students feel a strong sense of ownership of the makerspace, getting them to take extra responsibility for these activities takes little convincing.

In the beginning, however, there were instances, especially about sweeping, where most students balked and hesitated. Some of the activities at a makerspace can have socio-cultural elements that influence students’ response to them. This happened to be one such activity. For example, while the effects of the caste system in India are diminishing, there are still certain acts, such as sweeping, that are directly associated with lower castes or lower social status. These things are far from black and white, so not every student will feel that way, or to the same extent, depending on their own background and upbringing. Whenever the project researcher made the first move at picking up a broom to clean, however, the students always jumped in to take over without any hesitation. Such issues generally completely disappeared after a few days.

MATERIALS AND PROJECTS FEATURES

LOCAL SOURCING OF MATERIALS

When a makerspace is setup at a school, for both convenience and to economize the purchases, the tendency is to buy materials in bulk. While this would be reasonable in an ordinary setting, in a makerspace where most of the kids come from poor backgrounds, it is crucial that the materials in the space don't make them feel out of place. The choice of these materials should be such that they are relatable to the students. The disconnect can typically come from the prices of products from the standard or suggested brands, since they are quite expensive relative to local counterparts with inferior quality but significantly lower price tags, which is what these students are likely to be familiar with.

For example, in the beginning, several maker items were procured from Amazon, but one of the most common questions from the students at the makerspace was asking the price of the fancy looking items. When duct tape can cost significantly more than the daily household earnings for a child's family, it is understandable if that child is unable to relate to using such items freely. Therefore, it becomes crucial that, wherever possible, materials for the makerspace be sourced locally, even if that sometimes means compromising on the quality of the product. It is far more important that the students feel that the maker materials belong to them and that they belong in the makerspace.

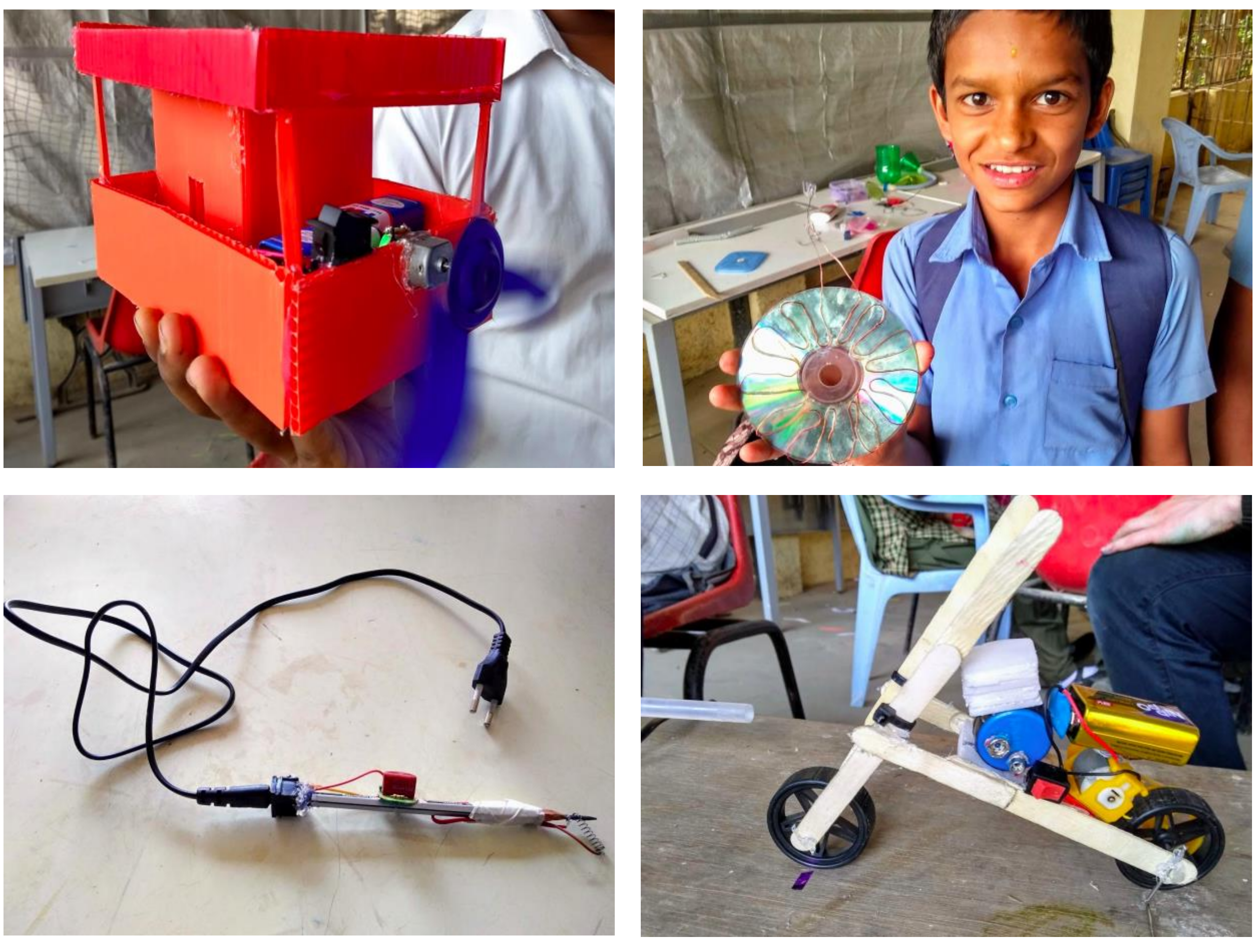

Figure 15: Examples of student maker projects

Choice of Maker Projects

The point where students are deciding on what projects to build and how this is approached by them and the adults in the space is one of the key factors in developing students' agency in the makerspace. This requires caution and it's necessary for the facilitator to maintain a fine balance, since either too much or too little intervention can damage the development of this sense of agency among the students. The facilitator needs to be a guide who provides helpful inputs through occasional mild nudges, such as:

1. by initiating ideas and thought processes in students if they feel stuck;
2. by giving them confidence about overcoming the skill gaps that they may currently have in using certain instruments;
3. by sharing exemplars for some existing maker projects; and
4. overall, by being vulnerable with them, acknowledging what the facilitator themselves doesn't know, so as to drive the point home for the students that everyone is there to explore, fail, learn, and grow together.

Norms Around Breakage

No matter how responsible and careful students and facilitators are, inevitably in a makerspace, things will break. In a setting where students are dealing with expensive tools and materials, breaking something can severely damage a child's confidence to act freely. Therefore, it is important that norms and expectations are made very clear early on with the students.

At the Namma makerspace, it was established with the students that while it is quite likely that something can break completely by accident, anything broken due to negligence would have consequences. The consequence would be evaluated based on the situation, designed with the person who broke the item, so that they fully understand its applicability and constructively respond to it. This meant that generally a breakage would be acknowledged as a mistake to be learned from, and in rare scenarios of active negligence, a typical consequence would be along the lines of either a temporary restriction of use of the tool or material for that student, or some kind of extra training for them on it, depending on the scenario. Such moments, when handled tactfully, are ideal opportunities for building a strong sense of responsibility among the students at the makerspace.

Community Building Features

Selection of Students

The early participants of the makerspace end up playing a crucial role in how others in the community perceive and engage with that makerspace. It is important therefore that this first set of students are selected with caution, ensuring that there is at least some initial alignment in the values that a student brings with them and those the makerspace intends to develop, thereby showcasing them to the school community at large. Besides, it is also important that the initial set of students be diverse in age, gender, and academic performance. Showcasing and celebrating this diversity in the makerspace from an early stage sends a strong signal to the student community that ensures that students can overcome stereotypes that society may have established for them and feel welcomed to join this community of makers.

Makerspace Access

In an ideal setup the demand for makerspace access among students at the school will be perfectly balanced by the number of students the makerspace can accommodate at any given time. Since that's rarely the case, it is important to ensure that some balance exists between maintaining cohesiveness and exclusive access to the students who remain regular constructive users of the space, and yet providing open access, or at least the opportunity of it, to all the other students at the school. Besides, it is necessary that the space does not run beyond capacity in order to accommodate a larger number of students, as that makes the whole experience unproductive and unenjoyable for everyone involved.

Figure 16: Students making tokens for their entry control system

Since at the Namma makerspace there were usually more students wanting to come in than what the space could accommodate, access was controlled and organized by setting up an entry token system. This involved placing a box at the entrance containing a counted set of different tokens (designed by the students as various smiley faces), wherein each incoming student had to pick a token before entering the makerspace and leave it in the box when they left. If there was no token in the box, it meant the makerspace was at capacity, and thus the next person must wait for someone else to leave before entering. While this may seem a bit harsh, the limit was kept to 14 tokens, which already was a stretch in the relatively small space where the makerspace was set up. Overall, this rewarded more dedicated early comers, provided opportunity to others if someone was absent, left early, or was taking a break, and gave students a healthy sense of privilege in being able to use the makerspace.

Trust Building

Any community run space needs to have a high degree of trust for it to remain productively functional. Since the educational makerspace necessitates that participants depend on each other's' cooperation and support from time to time, it is crucial that they feel that everyone shares similar goals and values with regards to the various activities within the makerspace. In a resource-constrained school where most things are otherwise inaccessible to the students and where the starting set of behavioral and ethical values may not be so even across the students, situations may arise where a breach of trust is observed. Such situations require firm yet delicate treatment and, as much as possible, it should be ensured that any actions taken should be based on a set of values already understood and agreed upon by the students.

One example of this was observed in the Namma makerspace when certain small materials, such as magnets, office supplies, laser pointers, and toy wheels began to disappear. After careful inventorying, it became clear that this was indeed a case of theft, but no one knew who might be responsible. Before a mild blame game among the students could fully ensue, it was quickly put to rest by instead taking it up as a design challenge for the whole group, to build a system of maintaining materials so that such a problem would not arise in the future. Posing it as a design problem prevented the feeling of embarrassment that emerged in some of the more dedicated students in the makerspace regarding this incident. While only a few steps emerged as an outcome, such as better monitoring of makerspace access by students who weren't regulars, maintaining a record of the inventory, more organized category-based storage of materials, and so on, that still turned out to be the last such incident to happen at the makerspace. Coming together to establish norms to prevent any wrongdoing in the future helped develop stronger trust and a deeper sense of ownership and belongingness for the makerspace among the students.

Engagement of the Teachers

Activities at any school are primarily driven by the teachers. Therefore, there is no chance of sustainability for an education project based in a school if the local teachers are not involved in the process. While it might seem ideal to have students maintain full ownership and functioning of the makerspace, the context of these schools contains such disparate levels of autonomy between principals, teachers and students that it becomes necessary to have a local champion of the makerspace among the teachers to have the makerspace be functional without continuous external help. Yet, teachers should not overdo their involvement, either, or else students can't break out of the existing student-teacher dynamic, and thereby miss out on developing any meaningful sense of agency and ownership of the space.

Therefore, at the Namma makerspace teachers were involved from day one. The project was fortunate to have certain teachers who truly became the local champions and voice of the project for the school administration. Yet in the day to day activities of the makerspace, there was almost no intervention from teachers. This allowed students to fully explore and express themselves freely in this space. Some of the teachers at the school who normally showed little to no interest in the activities at the makerspace were occasionally invited to come over for an informal exhibitory tour of the makerspace and the projects students had been working on. One such teacher was the school's PE teacher, who was particularly impressed by the students' work and the vibe of the space when he visited, and later even took the help of the various tools and students at the makerspace for preparing items for a school event for the Indian Republic Day celebrations.

Student Roles and Identities

The Namma Makerspace provided an outlet for not only hands-on learning but also exploring various identities for the students. Over time, many of the students ended up assuming roles and responsibilities that they naturally gravitated towards. This framing around identities emphasizes the importance of understanding learning beyond conceptual or skill acquisition. Learning and identity development are intertwined, such that learning transforms who we are and what we can do (Nasir & Saxe, 2003). These identities are almost like performances that we enact as we interact with others (Wortham, 2004). The students at the makerspace also exhibited their growth in learning through such identity development. While many of them started engaging at the makerspace in a shy or controlled way, they soon opened up and let their personalities emerge, which positively contributed to the effective functioning of the makerspace. Some of the examples of such identity building are shared below.

Silent Fixer of Broken Things

Santhosh's presence in the makerspace was hard to notice. He is not someone who either questions much or even shows what he has recently built. But every now and then, when something was in a dysfunctional state in the makerspace, the researcher would come in to notice that it had been fixed and no one really seemed to know who had done so. This applied not just to equipment such as burnt out hot glue guns or soldering irons, but even to small things like a loose section of the tarpaulin sheet that separates the makerspace from rest of the junkyard. It takes a keen eye, dedication, a desire to make things better, and a sense of ownership that makes a student take care of their makerspace in such a way. Santhosh's behavior is quite soft in its demeanor which can sometimes make him disappear among the crowd of overzealous students. Yet, given his tendency to take initiative in making things better, he proved to be one of the most resourceful students in the makerspace. He built some of the most elaborate projects in the makerspace, such as a small version of an Indian house made of wood with appropriate proportions that had electricity generated from a small hand-run dynamo-like setup, capable of powering some lights and a fan when one rotated the motor. Interestingly though, one of the teachers who was initially opposed to the idea of students spending time in the makerspace, had used Santhosh as the main example for students who because of poor grades and lack of sincerity around studies, needed to spend less time in such places outside of class, when in the makerspace Santhosh was clearly hardworking and most eager to learn.

Figure 17: Santhosh with one of his early projects

Flagbearer for Girls

During the first two days of setting up the makerspace, only boys showed interest. Initially, even some of the teachers were of the opinion that activities that generally dealt with hardware or electronics were all "boy stuff," so it's better that girls are shying away from it. The girls in the school could typically be found sitting in a circle in their dimly lit arts room, where they would either be sewing something or drawing things on chart papers. While there is nothing wrong in working on anything that one does out of their interest, but the gender stereotyping of student tasks in the school was too obvious to miss. Even the biology teacher in the school, who was the strongest local champion of the makerspace and fundamentally related to everything that making stands for, also gave up saying that the girls did not show interest despite her encouragement. But a day later, she brought Vrinda with her, who she said was keen on checking out what was happening in this space. Seeing this as a great opportunity for bringing gender diversity to the makerspace, basic norms of behavior were discussed with the rest of the group so that she felt welcomed in the group and a natural part of it. She took great interest in all the activities, helping in all tasks related to building the makerspace, including woodworking, cleaning, and electronics. In a couple of days, she also started bringing her best friend to the space, and now there were two girls helping with the space setup and also working on a project to build a vacuum cleaner using metal sheets, a plastic bottle, and electric motors. Seeing two girls already at work in the makerspace, more and more girls in the class showed interest and joined in, and within two months the number of girls equaled the number of boys in the makerspace. Being an extremely shy and soft-spoken girl, Vrinda may not immediately look like a leader, but at the Namma makerspace, her desire to break from the expected norm of what girls are or are not supposed to do paved a natural path for other girls to follow.

Figure 18: Vrinda with her hydraulic multi-level racing track

Man of all Logistics

Suman is a big bundle of energy. He was one of the first people to engage with the makerspace work and was almost the face it. A trustworthy student, who reveled in taking on various responsibilities such as maintaining access to the makerspace, keeping track of what materials are there and what is running short, and even sometimes liaising with teachers. He was two years older than most other students, as he had flunked his final exams twice, and academically his performance wasn't that great this year either. Friendly to all, his jokes and cheerful behavior brought special energy into the makerspace. Though it took some time, it became increasingly clear that what attracted him to the makerspace was not necessarily building things, but the social aspects of it and the opportunity to manage the place. Despite his key role in the makerspace, his engagement with the maker activities remained somewhat superficial. He would make something, but one could gather from the discussions with him that he did not see much value in what he had built or particularly enjoy the building process. His interests truly lay in the act of being in the space, interacting with everyone, and feeling like he was part of something important, where his presence was valued and he was treated with respect. Multiple subtle and upfront efforts from the researcher of getting him interested in the concepts behind the maker projects brought little change. Particularly, there was almost a visceral reaction

Figure 19: Suman, the happy boy

to anything that resembled their school studies. Thankfully, Suman is a complete showman, which means that any time there was an opportunity to present something, he would be in front, which also meant that inevitably he ended up picking up a lot of conceptual things along the way that someone showcasing a project would need to understand.

Mentor Carpenter

Figure 20: Naveen helping the team build a mobile storage cabinet

Naveen was one of the few kids from the eighth grade in the group, since most of the other kids who are regular participants of the makerspace were in grade 9. Naveen's father is a carpenter by profession and had taught him a few woodworking skills the previous summer. Since in the makerspace all of the furniture, including the storage cabinets, were built by the students, Naveen became the de facto mentor and leader for all the students who engaged in woodwork. This was one of the examples of the peer-to-peer learning and mentorship models that emerged in the Namma makerspace as students began working on different projects. While not shy, Naveen is also not someone who wants to be the center of attention. He is quiet and keeps mostly to his work. Yet when it came to building the storage cabinets in the makerspace, he led and guided the whole process in a very thoughtful way, helping everyone plan, showing others how to do things, and then letting them take their time with it. He was patient with the mistakes that others made, such as when a calculation error led to a big gap in the final attachment of two doors on one of the cabinets, rendering it almost unfixable, he calmly suggested that they let that one be an open cabinet and started building a new cabinet, taking into account the measurements of the two doors. In a school where class seniority significantly matters for how one acts with other students, the fact that the ninth graders felt comfortable being led by an eighth grader is a testament of Naveen's sound leadership skills.

Conclusion

This implementation of the thrifty makerspaces project was aimed at developing a systematic understanding of various factors involved in building a sustainable educational makerspace in resource-constrained schools. The goal was to create a prototype of such a makerspace from scratch at a school, and in the process identify different elements involved and how they interact with each other. One of the key premises that this implementation was based on was that conducting maker-based learning effectively in a resource-constrained school does not necessitate the use of expensive equipment and materials. The project implemented one such prototype of an educational makerspace in a government school in

Bangalore, India. This report details the elements involved in that process, the successes en route, and some of the underlying challenges faced during this implementation.

This implementation of the project provides information on processes and criteria that are crucial to keep in mind when building a makerspace from scratch in resource-constrained schools. It provides inputs around various features within a makerspace, pertaining to the space design, materials and projects, and community building strategies. As presented in the findings, small things can have big effects when it comes to engaging students and building a strong sense of ownership for the makerspace in them. One of the hardest parts in such an implementation is for the participating adults to minimize their involvement and let the students truly drive the makerspace activities. Choices around the location of the makerspace, sourcing of materials, values and norms of behavior, and involvement of the teachers and the broader school community all collectively have a large impact on effective functioning of the makerspace. The participating students showcased enhanced agency by taking up roles and responsibilities that naturally aligned with their identities and building projects around their interests. The pivotal role of the presence of a local champion at the school also became evident during the implementation, and any future implementation of such makerspaces in schools should prioritize finding local champions.

When starting a makerspace from scratch in such a context, there is never a shortage of challenges. Throughout the implementation of this project, many such challenges were faced. One big challenge came when the principal was transferred to a new location, and the project lost its biggest support at the school. While this and the numerous logistical challenges, such as problems in running a makerspace in the absence of much of the basic infrastructure and supplies, did make things harder, nothing hurt this project more than losing the local champion at the school. This happened at the end of the implementation year, when the biology teacher also decided to transfer to a different school. Also around the same time, after a long wait for a new principal, the local education department appointed one of the senior teachers at the school as the new interim principal who was one of the teachers who had been critical of the project. Overall, with the two biggest supporters of the makerspace project at the school gone, and the new administration head not supportive of the project, it was decided not to run a second year of implementation of the project at this school site. In the second year, the project would instead focus on providing academic support to the Atal Tinkering Lab schools that are currently being funded by the Indian government to help set up an educational makerspace in each selected school.

While innovations in education such as maker-based learning are impacting the schools across the world, the education systems in many developing countries, and particularly the resource-constrained government schools in India, remain severely outmoded in their pedagogical practices. For a country with the largest population of school-age children in the world, it is imperative that students are equipped with the necessary skills and mindsets for the future, or else this demographic dividend can also end up being the biggest burden for the country. In a rapidly changing world, where even the relatively near future is becoming increasingly unknowable, the best way to prepare a child for the future-success in life is to provide them key life-skills and develop the right mindsets. Educational makerspaces have the potential to provide the most optimum setup and environment for a child to develop these attributes at a school. Therefore, understanding what it takes to establish and sustainably run a makerspace in resource-constrained schools remains an important area of research to explore.

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References

Jackie Gerstein. 2014. Cultivate a growth mindset with these 6 strategies. Noodle. Retrieved from https://www.noodle.com/articles/these-6-strategies-will-promote-a-growth-mindset-in-your-kid

Kylie Peppler, Erica Halverson, and Yasmin B Kafai. 2106. *Makeology: Makerspaces as Learning Environments.* Routledge, New York

John Seely Brown, Allan Collins, and Paul Duguid. 1989. *Situated cognition and the culture of learning.* Educational Researcher, 18 (1), 32-41.

Mitchel Resnick, and Eric Rosenbaum. 2013. Designing for Tinkerability. In Honey, M., & Kanter, D. (eds.), *Design, Make, Play: Growing the Next Generation of STEM Innovators,* pp. 163-181. Routledge.

Shirin Vossoughi, Meg Escudé, Fan Kong, and Paula Hooper. 2013. *Tinkering, learning & equity in the afterschool setting.* Paper published as a part of FabLearn Conference Proceedings. Stanford University.

C K Prahalad and R A Mashelkar. 2010. Innovation's Holy Grail. *Harvard Business Review.* Retrieved from https://hbr.org/2010/07/innovations-holygrail

NITI Aayog, Annual Report, 2016-17. New Delhi. Retrieved from http://niti.gov.in/writereaddata/files/document_publication/AnnualReport_16-17_ENGLISH.pdf

Dhananjay V Gadre. 2018. Path-Breaking Atal Tinkering Labs: Why It Is Time For Course Correction. Swarajya. Retrieved from https://swarajyamag.com/ideas/path-breaking-atal-tinkering-labs-why-it-is-time-for-course-correction

Sanchit Misra. 2016. Reforms set to seep into India's schools. *Nature* 536, 148. http://doi.org/10.1038/536148a

Kimberly Sheridan, Erica Rosenfeld Halverson, Breanne Litts, Lisa Brahms, Lynette Jacobs-Priebe, and Trevor Owens. 2014. Learning in the Making: A Comparative Case Study of Three Makerspaces. *Harvard Educational Review* 84, 4: 505–531. https://doi.org/10.17763/haer.84.4.brr34733723j648u

Breanne K Litts. 2015. Making learning: Makerspaces as learning environments. Ph.D. Dissertation. University of Wisconsin-Madison, Madison, WI. UMI Order Number: 3672348

Ray Oldenburg. 1989. *The Great Good Place: Cafes, Coffee Shops, Community Centers, Beauty Parlors, General Stores, Bars, Hangouts and How They Get You Through the Day*. Paragon House, New York.

Steven R Kurti, Debby L Kurti, and Laura Fleming. 2014. The Philosophy of Educational Makerspaces. *Teacher Librarian* 41, 5: 8–11.

Lauren Britton. 2012. A Fabulous Laboratory: The Makerspace at Fayetteville Free Library. *Public Libraries Online*. Retrieved from http://publiclibrariesonline.org/2012/10/a-fabulous-labaratory-the-makerspace-at-fayetteville-free-library/

MakerEd. 2014. MENTOR Makerspace Project: Levels of Tool Costs for Makerspaces. Retrieved from https://makered.org/blog/mentor-makerspace-project-levels-of-tool-costs-for-makerspaces/

Lois Hetland, Ellen Winner, Shirley Veenema, and Kimberley M Sheridan. 2007. *Studio Thinking: The Real Benefits of Arts Education.* Teachers College Press, New York, NY.

Etienne Wenger. 1999. *Communities of Practice: Learning, Meaning, And Identity.* Cambridge University Press.

Na'ilah Nasir, and Geoffrey Saxe. 2003. Ethnic and Academic Identities: A Cultural Practice Perspective on Emerging Tensions and Their Management in the Lives of Minority Students. Educational Researcher. 32. 14-18. 10.3102/0013189X032005014.

Stanton Wortham. 2005. Learning Identity: The Joint Emergence of Social Identification and Academic Learning. 1-305. 10.1017/CBO9780511810015.