# *Jugaad* Thinking: Contextualized Innovative Thinking in India Through Science, Technology, Engineering, and Mathematics (STEM) Education?

**Geeta Verma**

**Abstract** This chapter briefly explicates the cultural, social, and historical ideas related to the term *Jugaad* in Indian society and its integration with contemporary innovation conversations. A distinction is made between *Jugaad Solutions* and *Jugaad thinking* in the context of business and technological innovations. The author argues for integrating Jugaad thinking within formal education, specially in the STEM learning experiences of K-16 students in India, since Jugaad conversations are an integral part of living (and being) in Indian Society. Science, Technology, Engineering and Mathematics (STEM) education provides affordances to integrate Jugaad thinking and may contribute to the existing cultural and social capital of school-age children. The chapter highlights implicit ideas underlying Jugaad thinking and interfaces them with the practices of science. Overlapping ideas such as creativity, innovation, and imaginative ways of thinking between Jugaad thinking and scientific practices are highlighted. Finally, the author discusses alternative and inclusive spaces for STEM learning in order to integrate Jugaad thinking into STEM education.

## Introduction

I open this chapter with a vignette shared by a person very close to me. Mili, a female, lives in a co-operative housing society in the Southwestern part of Delhi, India. As Mili shared this particular event, the first thought that came to my mind was 'kya jugaad kiya' (What an innovative solution!!). Mili is a Physical Education teacher at a central government school and she teaches physical education to K-12 students. In addition, she is assigned administrative responsibilities to help run the school that includes managing the annual school inspection that takes place at the school. As it happens, most years the Principal, in consultation with the teaching and administrative staff, decided to offer refreshments to the visiting authorities at the end of their visit. Mili is also known as a great cook so she offered to cook

G. Verma (✉)
University of Colorado Denver, Denver, USA
e-mail: geeta.verma@ucdenver.edu



R. Koul et al. (eds.), *Science Education in India*,
https://doi.org/10.1007/978-981-13-9593-2_11

'Sabudana ki Khichdi' (Tapioca Pearls)—a dish well known in many parts of India. Mili's Sabudana ki Khichdi is very popular and she is extremely proud of the dish. The dish requires Mili to do preparation the night before and cook the dish in the morning. Mili woke up early next morning (4.30 a.m.) to cook the dish and realised that the preparations from the night before had totally failed—the reason being that she bought the Sabudana (Tapioca) from a different grocery shop. Mili couldn't go to school without a dish and had to quickly think on her feet to come up with a different dish. She decided to prepare another dish called 'Poha' (flattened rice) as it's quick and easy to prepare. However, this dish needed additional ingredients such as potatoes that she didn't have at home. It was a conundrum to find potatoes at 5 a.m. in the morning as all the markets and shops were closed at that hour. As she contemplated finding solutions to her problem, Mili looked out the window and saw a gentleman doing his morning walk in her co-operative housing society. She called the security personnel at the gate to speak with the gentleman when he came around. Mili asked the gentleman if he happened to have potatoes at his house and if she could borrow a few to make her dish. Of course, the gentleman obliged and Mili was able to get the missing ingredients for her new dish. As I was listening to the story, I couldn't help but think of the role of necessity, creativity, risk taking and innovative thinking in this situation and Mili's keenness to find a solution. The frugality and flexibility of the solution is what folks in India would call 'Jugaad'—a creative and innovative solution to everyday problems that one faces.

Many readers in India (and elsewhere) will relate to this story well as they too have had to find creative solutions in similar situations. One may argue that in tight-knit communities around the world, folks draw upon the community resources, including its members, to get help and solve problems. The distinction I want to make using this vignette is that Mili personally didn't know the gentleman as a part of her social circle. Both shared a common living space (a cooperative housing society), however, Mili found a Jugaad solution to her problem by putting together resources that wouldn't typically be a part of her solution. In other words, finding a way to solve her problem (getting potatoes at 5 a.m. in the morning), Mili had to come up with a Jugaad solution that included: (1) taking a risk by reaching out to an unknown gentleman; (2) tapping into his domestic resources (potatoes) and (3) getting him to agree to share his domestic resources with her. I classify this as a Jugaad solution as this is not the usual way one goes about securing ingredients for cooking.

A need for Jugaad solutions occur due to various reasons such as (1) scarcity or unavailability of resources; (2) a need for reallocation of the available resources to solve immediate problems; (3) institutional, societal, and economic barriers that doesn't allow for obvious (and mainstream) solutions and (4) being in a challenging situation similar to that of Mili's. In other words, as people find themselves in exigent situations that are on a continuum from being easily surmountable to very difficult to solve, they find frugal, flexible, and creative solutions. In India and other emerging economies the idea of Jugaad is very prevalent. Radjou, Prabhu, and Ahuja (2012) share that Brazilians use the term 'jeitihno' (jeitinho is the diminutive form of jeito, which comes from the expression dar um jeito, meaning 'to find a way'), Chinese call it 'zizhu chuangxin' (Chinese: 自主创新; pinyin: zìzhǔ chuàngxīn; literally:

endogenous and/or indigenous innovation), Kenyan's refer to 'jua kali' (Jua Kali in Kenyan Kiswahili is 'fierce sun'; the actual meaning is the Kenyan word for 'git er done', or a person, businessman, or entrepreneur that can undoubtedly fix or practically do anything upon request). In summary, in an ideal world all societies and its members shouldn't have to draw upon Jugaad solutions (or a version of it) since they would have access to abundant resources leading to ease of living. However, it is clear that Jugaad solutions continue to persist in various societies due to reasons (e.g. poor governance) and discussing those are beyond the scope of this book chapter. In this book chapter, the author works with the following assumptions: (1) there is an existing opportunity gap between resources and members of society in emerging economies; (2) traditional expensive research and development (R&D) models that may not work in resource-strapped economies; (3) people are willing and capable of finding flexible, innovative, and creative solutions to their problems; and (4) the opportunity gap could be reduced by acknowledging, valuing, and integrating local knowledge systems into creative problem solving.

## Jugaad—A Contested Term: Many Meanings and Interpretations

Jugaad is a Hindi word which is difficult to translate into English because it draws upon the shared Indian experience of frugal and flexible solutions to find simple and creative solutions to problems that people experience on a day-to-day basis. Jugaad reflects a shared history of ingenuity in the face of challenges in Indian society and other emerging economies. With a long history of foreign rule and colonisation in India, Jugaad, as a concept, is a way of thinking or an ability that may have been created in the psyche of the society for people to solve problems under conditions of shortage (resources), constraints, and a dearth of basic facilities.

There are many definitions of the word Jugaad—a colloquial Hindi word that roughly translates as 'an innovative fix: an improvised solution born from ingenuity and cleverness' (Radjou, Prabhu, & Ahuja, 2012, p. 4). Nelson (2018) presents Jugaad as a Hindi feminine noun, 'colloquial meaning: a quick fix, improvised or home-made solution, a frugal innovation, a temporary hack, botch jobs, by any means necessary, corruption. Provision, means of providing. To gather together at the necessary means to do something' (p. ix). Jugaad could also refer to making new things from materials rendered useless, inventing new tools using everyday materials, and even ingenious way to get around rules or the system (e.g. a friend giving you a missed call on the cell phone to let you know that they have arrived at a common meeting point without having to pay for the cost of a call). Therefore, the vignette I shared to open the chapter could be categorised as a Jugaad solution (clever improvisations to solve everyday problems that may or may not be legitimate and law abiding).

The word Jugaad may have origins in the Punjabi language—it was used as a noun to describe a makeshift vehicle which was a combination of a diesel engine and a cart. This vehicle is motorised and can sometimes carry 20 people, despite being powered by a noisy irrigation pump/motor, having wooden planks as seats, and being put together from old motorbike pieces. See images below:

Images 1 and 2: Jugaad vehicles

The ingenuity behind this makeshift vehicle captures the thinking behind Jugaad solutions and now has spurred conversations of innovation and creativity in various walks of life. Many books have been written on the topic of Jugaad innovations—mostly focused on the business sector. Here are some titles to provide a context to the reader: Steps to Innovation: Going from Jugaad to Excellence (Dabholkar & Krishnan, 2013); Jugaad Yatra: Exploring the Indian Art of Problem Solving (Nelson, 2018); Jugaad Innovation: A Frugal and Flexible Approach to Innovation for the 21st Century (Radjou, Prabhu, & Ahuja, 2012); and Indian Innovation: 20 Brilliant Thinkers Who are Changing India (Agrawal, 2018).

There appears to be two schools of thought related to Jugaad conversations. The first group distinguishes between the value of Jugaad (and Jugaad solutions) as a symbol of India's innovative abilities versus the second group who argue that the persistence of Jugaad (and Jugaad solutions) symbolises a lack of progress in post-independence India, leading to continued suffering in various strata of society. This, in turn, means that members of society have to continue to 'make-do, driven by a single cause, lack of resources or lack of access to necessary resources, which can be inputs, but mostly money' (Review of Nelson's Jugaad Yatra by Shashtri, P., Financial Express, July 29, 2018).

The first group of writers, scholars, and thinkers believe that positive Jugaad solutions can play a huge role in providing practical solutions in fields such as agriculture, healthcare, energy and the financial sector—solutions that are affordable and accessible to the masses. They argue that, in the past, Jugaad solutions were considered temporary, localised and didn't occupy a credible institutional place in educational settings and/or the business sector. Furthermore, this group recognises the value in scaling up and replicating Jugaad solutions to (1) meet the needs of economically underprivileged and disadvantaged citizens in India; and (2) meet the societal goals of providing inclusive basic education, health, and food security needs. This group may make a distinction between 'good' or 'bad' Jugaad solutions. Good

Jugaad solutions could include examples of indigenous products and ideas that create affordable solutions for economically underprivileged and disadvantaged citizens (e.g. the MittiCool Refrigerator by Mansukhbhai Prajapati, a preventative eye care device by Shyam Vasudev Rao, $CO_2$ removal technology by Prateek Bomb & Aniruddha Sharma). Bad Jugaad entails breaking rules and laws of the land to create solutions and deliver low-quality products that affect public safety (e.g., adulterated medicines), are flawed in principle (innovations that solve everyday problems but cause pollution, undercut innovations for scaling up), prevent systematic and scalable innovations (inability to document innovation for copyright and/or patenting), and overall compromise the quality of the products, services, and/or experiences for the public.

The second group of thinkers believe that the continued existence and persistence of Jugaad (and Jugaad solutions) is strong evidence that 'the circumstances of a society are so bad that its smart people are doing what smart people in other societies do not have to do' (Joseph, 2018). This group of thinkers agree with the first group, that Jugaad solutions are helpful in creating temporary fixes for certain situations, but they may not be scalable solutions and may prevent new inventions from being discovered. This group argues that there are no good or bad Jugaad solutions—all Jugaad solutions are mediocre—since they involve cutting corners and practicing frugality. This group of thinkers present multiple examples of systemic failures of inventions (and circumstances) that were driven by Jugaad solutions—for example, failure of the Akash tablet, cheap phones, proto-Artificial Intelligence to translate languages, and medical tragedies being caused by Jugaad solutions. They argue that giant corporations such as Apple and Google have been able to solve many of these problems due to their systematic investment in research and development leading to high impact innovations that are sustainable and scalable.

Based on discussion so far, it is important to make a distinction between Jugaad solutions and Jugaad thinking. Jugaad solutions are considered to be frugal, temporary, flexible, creative solutions in a place such as India where there could be a dearth of resources (discussing these reasons is beyond the scope of this chapter). It is the make-do solution. Jugaad solutions are revered and accepted as a part of life in places such as India. However, Jugaad solutions may not provide long-term solutions to the persistent problems faced by society (e.g. the transportation, sanitary/waste, and/or health sectors). This may be due to the fact that many challenges that have localised short-term solutions are challenging to scale up and may not lead to new inventions that add to the intellectual capital of society. They may be just good for localised temporary solutions. Highlighting the shortcomings of Jugaad solutions is important. However, it is important to note that products and solutions that come out of research and development (R&D) efforts from giant corporations may be too expensive for everyone to access. In addition, the price that people will pay to use these products may be too high (think of the personal data that one inadvertently shares with large corporations such as Facebook and Google by using their 'free' products and services) and ethics driven discussions that are taking place around the world.

Jugaad thinking, on the other hand, is a way to approach an intractable problem. It is innovative, allows for thinking outside the box, leads to solving problems, and establishes new ways to approaching an issue. Focusing on Jugaad thinking allows one to seize opportunities in such circumstances to not only to solve problems but to create an intellectual knowledge base that could be shared with families, neighbours, communities and society at large. Many existing innovations created by Indians may fall into this category. Some examples include Offline Internet on Mobile phones (by Innoz), Science for Society (Care Mother Testing Kit and Digital Platform for providing Pregnancy care), Road Management using plastic waste (by KK Plastic Waste Management), and Location tracking without GPS (by Sriram Kannan) (Agrawal, 2018).

It is challenging to make a distinction between Jugaad solutions and Jugad thinking. The boundaries clearly blur since a Jugaad solution is probably driven by Jugaad thinking. How do we then discern the difference between the product (Jugaad Solution) and the process (Jugaad thinking)? Maybe there is a THIRD way to think about this dichotomy. We live in a global world and it is impossible to escape from the influences of globalisation whether it is trade, travel, media and entertainment, and/or buying products created by multinational companies. As a result of globalisation, products (and services) created by the R&D efforts of multinational corporations are sold in emerging economies, since these economies are profit-generating markets. However, these corporations have to draw upon local talent to not only successfully sell these products but also to install and service the products. The following example may help to explain this further.

Many upwardly mobile middle-class Indian families buy various household electronics (e.g. washing machines, air conditioners) from large non-Indian companies. However, almost always a variation in the installation process of these washing machines, water purifiers, or air conditioners is necessary in India homes. As an example, when installing a washing machine, the quality control of the core installation idea is maintained by the corporation selling the product, however, the person on the ground is allowed to engage in Jugaad thinking and create localised solutions to successfully install the washing machine. This could be due to many factors, one of which being that many Indian houses may not be retrofitted to easily install a washing machine or an air conditioner. The localisation or contextualisation of Google maps is another example. Google maps robustly integrates landmark use along with street names to customise the Google map experience in India, as residents depend more on landmarks to navigate street maps.

In other words, these big corporations have drawn upon Jugaad thinking (with the help of local talent) to improve their products and user experience. In addition, they have most definitely used this information to inform their Research and Development (R&D) processes to customise products (and services) to cater to the needs of the local population. The innovativeness and customisation of products and services launched in emerging economies comes from integrating local and contextualised knowledge to make these products and services relevant and successful. Therefore, Jugaad thinking contributes tremendously to improved products and services from large corporations. The question to pose here is whether these products could be labelled Jugaad products since they relied heavily on Jugaad thinking to either improve the product itself or influenced successful use of the product.

It can be argued that the revamped Jugaad products/solutions create a hybrid or a third space (Bhabha, 2012; Frenkel, 2008) where large corporation's 'know how' weaves inextricably with indigenous (a.k.a local) knowledge claims (Jugaad thinking in this case) (Pansera & Owen, 2014). Therefore a distinction needs to be made between a parent product which is non-indigenous in nature and a version of the parent product that integrates Jugaad thinking and becomes an indigenized version of the same product. Acknowledging and honouring this distinction is not only crucial but an ethical thing to do since most products these corporations are selling in emerging economies are indigenized versions of their original product. Therefore, there are three way to address the mediocrity issue related to Jugaad solutions by (1) expanding the boundaries of our understanding of what constitutes Jugaad solutions by identifying the contributions of indigenous knowledge claims (e.g. Jugaad thinking); (2) seeking copyright, trademarking, and/or patenting for the indigenous versions of productions and solutions; and (3) revising our understandings of Jugaad solutions by instituting a few qualifiers (e.g., they need to be law-abiding, do no harm to the public) and provide scalable and affordable solutions to the problems faced by millions of Indians.

To move this conversation further, it might be helpful to become familiar with innovations that may have their origins in Jugaad thinking. Agrawal (2018) discusses 20 such innovations in his book and some of these innovations appear to have a strong connection with indigenous knowledge, for example, clay pottery (MittCool Refrigerator) and handloom weaving (low cost sanitary pad) that are very contextual to Indian society. These innovations were created by students, entrepreneurs, and people practicing traditional crafts and clearly outline how Jugaad thinking could positively influence innovations to create affordable solutions to the problems faced by millions of Indians. Discussing two of these innovations may provide contextual understanding and an argument for making Jugaad thinking the starting point for creating Jugaad solutions that are indigenous, sustainable, and scalable.

The first example, the MittiCool Refrigerator innovation by Mr. Mansukhbhai Prajapati, clearly presents an example of an innovation that has roots in existing indigenous knowledge—using clay pots to cool water during the summer months. Mr. Prajapati came from a traditional clay potter's family and, through intense trials and tribulations, ended up creating what may be called the poor man's refrigerator made with mitti or clay (MittiCool refrigerators). He achieved this with the help of the GIAN (Grassroots Innovation Augmentation Network), an incubator of grass-roots innovations and traditional knowledge. The Mitticool refrigerator is a patented product that allows fruits and vegetables to stay fresh for up to five days, milk for up to 2 days, doesn't use any electricity and costs only about Rs. 3000 (approx. $40).

The second innovation is by Mr. Arunachalam Muruganantham, creating a low-cost sanitary pad making machine. In fact, a movie has been made about his life featuring the actors Mr. Akshay Kumar and Ms. Radhika Apte (in addition to other actors). This innovation addressed the issue of menstrual hygiene that is under-acknowledged and under-discussed in Indian society. Mr. Muruganantham had a background as a handloom weaver. He became aware of the challenges faced by women in India during the menstruation days after his marriage. His attempts to create affordable sanitary pads is heartbreaking yet inspiring. This innovation led to the formation of Jayashree industries that now manufactures sanitary pad making machines (ranging from Rs. 75,000–200,000) which are capable of producing 500 sanitary pad per day. The pads are sold at Rs. 2 per piece and the business model employs women in self-help groups who are able to earn Rs. 5000–10,000 per month.

I share these examples to make an argument for foregrounding Jugaad thinking to solve societal problems, to meet the basic needs of underprivileged and disadvantaged citizens, and, to create a culture of inclusivity for every citizen. As India and other emerging economies grow, many problems will need to be solved. The high cost of the R&D model in western nations is going to be a deterrent. However, foregrounding Jugaad thinking could lead to creative and innovative solutions and create these third or hybrid spaces where people's needs and aspirations align through their engagement in identifying and solving their own problems.

Creating Jugaad solutions and engaging in Jugaad thinking has become an integral way of life for people in India and other societies. Reasons (e.g. post-colonial legacy, lack of resources, lack of basic infrastructure or other reasons) that sustain this way of being is beyond the scope of this book chapter. It is important, however, to find ways to (1) establish an asset-based approach for Jugaad thinking rather than having a deficit perspective; (2) find ways to value Jugaad thinking for problem-solving and creating solutions that are sustainable and scalable; (3) engage with Jugaad thinking as an innovative way to examine the world around us.

## Education, Science Education: Enactment and Practices

One way to interface with Jugaad thinking in India is to create learning opportunities for all students during formal (and informal) science education. This brings me to briefly discuss the experiences young people in India have during their formal education. I can't speak for all content areas but can speak confidently about the affordances provided in studying science. Science is a subject where creativity, out-of-the-box thinking, and innovative thinking should be revered and valued. However, students often have science learning experience that are sterile, boring, out-of-context, loaded with academic language, distant from students' lives, and examination driven alienates a large majority of students from science.

The students' who persist through these experiences either have grit and determination and/or are naturally drawn to the study of sciences. In other words, the educational offerings deprive many students of opportunities to learn critical thinking skills and acquire scientific literacy through the study of science. Whether we want our students to become scientists, scientifically literate, make informed decisions about science-related issues, or participate in the economic, social, and cultural hues of society, access to quality education and quality science education is imperative. It is great that in a young country like India, the demographic dividend (Mitra,

2017) works in its favour. With over 250 million students enrolled in K-12 schools and over 800 million citizens aged under 35, it is of the utmost importance that we provide meaningful opportunities for students to develop skills and competencies that are crucial to the future of the country.

In the next few sections, I would argue for providing opportunities for students to engage in innovative ways of thinking by engaging with STEM education during their formal (and informal) education and explicitly for interfacing with Jugaad thinking. For the purpose of this chapter, I will be using STEM education and science education interchangeably. I will argue for embracing and integrating Jugaad thinking into our formal science education in order to take advantage of this demographic dividend as well as to share the history of creative problem solving and innovation using Jugaad thinking. We can't expect students to suddenly demonstrate innovative, creative thinking, and problem-solving skills in higher education or work environments without having these experiences in the K-12 setting.

I will briefly discuss the nature of scientific enterprise by reviewing the literature, mostly from the fields of philosophy and history of science. This allows me to make a distinction between the nature of scientific enterprise and the nature of school science. I specifically invoke writers such Beveridge (2004), Chalmers (2013), and Kuhn (2012) to discuss the role humans play in the enactment of scientific enterprise. These authors discuss the attributes that practicing scientists possess to be successful in their work as they make sense of the natural world around them. I share a few examples where creativity, innovation, chance, and luck played a huge role in scientific discoveries and inventions and connect these ideas to Jugaad thinking. Based on this literature review, I argue for the creation of learning opportunities in the science classrooms (and in STEM fields) for creativity, innovation, imagination, perseverance, tenacity and collaborative ways of thinking. I also argue that students need to have exposure to diverse disciplines (social sciences, arts, literature) for them to draw upon the virtuosity learned elsewhere and transfer these skills productively to the science classroom. These ideas align very much with Jugaad thinking and we should aspire to create spaces for students to meaningfully participate in school science.

A scientist's mind needs to be well prepared and imaginative to identify seemingly insignificant results or events and sometimes new discoveries come from these unexpected places. Bryson and Roberts (2003), in 'A Short History of Nearly Everything' discussed attributes of people who contributed to successful scientific advancements. These authors clearly indicate that many famous and successful scientists had diverse backgrounds. As an example, Edmond Halley was a well-known astronomer but he also had a successful career as a cartographer, geometer as well as working as a sea captain (Bryson & Roberts, 2003). Beveridge (2004) made a similar point by sharing the diverse backgrounds of many scientists who made significant contributions to the scientific enterprise. Beveridge (2004) discussed in various ways how scientists create new explanations—specifically, the prolonged process of trial and error that may be required to approach problems. The process of creating novel scientific solutions based on trial and error requires them to draw upon their diverse life experiences (including their educational background). Scientists' ideas grow as they engage with their peers and others who do similar work but have diverse perspectives.

Many of us hold misconceptions about who can become a scientist and 'do' science. Dalton's life and his scientific contributions is a good example. Dalton's ideas about the atom's size and structure and how it fits together made him famous in 1808. Since scientific knowledge builds on prior knowledge, it allowed other scientists (Rutherford, Chadwick, and Thomson) to create new scientific discoveries. However, when French Chemist P. J. Petterlier travelled to Manchester to meet the atomic hero, he was astounded to find Dalton teaching elementary arithmetic to boys in a small school and being extremely humble about his accomplishments. Dalton avoided all honours but was elected to the Royal Society against his wishes and was given a government pension.

The example of Rutherford, the well-known physicist, shared by Bryson and Roberts (2003), is also worth discussing. According to Bryson and Roberts (2003), Rutherford was not an especially brilliant man and in fact was pretty bad at mathematics. His long-term colleague James Chadwick (discoverer of the neutron) indicated that Rutherford wasn't particularly 'clever at experimentation' either (p. 138). However, Rutherford was tenacious and open-minded and these attributes allowed him to be daring and gave him the capabilities to work harder and longer at most problems and to be 'more receptive to unorthodox solutions' (p. 138). His major breakthrough came during tedious work and long hours counting alpha particle scintillations on a screen. Being engaged in this tedious work allowed him to be the first one to see the power of energy inherent in an atom.

Beveridge (2004) discussed the role of imagination, curiosity, and chance in science. He argues that imagination allows us to not only lead but stimulate new efforts to visualise future possibilities. According to Beveridge (2004), imagination gives life to facts and ideas—which differs from dreams and speculations that are considered idle fantasies. Beveridge shared several examples in support of his argument for creating a place for imagination in science and science teaching. Some of these examples include:

> Newton's passage from a falling apple to a falling moon was an act of a prepared imagination. Out of the facts of chemistry, the constructive imagination of Dalton formed the atomic theory. Davy was richly endowed with the imaginative faculty, while with Faraday its exercise was incessant, preceding, accompanying and guiding all his experiments. His strength and fertility as a discoverer are to be revered (p. 58).

Similarly, curiosity as an instinctive attribute is a part of human experience. This experience could be guided toward seeking an understanding of the natural world or understanding of things or relationships. In science, explanations are used to connect new observations or ideas and to develop our understanding of current ideas. The desire to make sense of data and their underlying principles are driven by curiosity on the part of the scientist.

The role chance plays in scientific discoveries in an overlooked phenomenon. Beveridge (2004) shared multiple examples but the invention of the principle of immunisation is probably the most profound. Pasteur's research on fowl cholera was interrupted due to him taking a vacation, and he found that the cultures had become sterile upon his return. He tried to revive the sterile cultures by sub-inoculating them into broth and injecting them into fowls. The birds were not affected by the sterile cultures but he decided to re-inoculate the same fowls with a fresh culture. To everyone's surprise, 'and perhaps even of Pasteur, who was not expecting such success, nearly all these fowls withstood the inoculation, although fresh fowls succumbed after the usual incubation period' (Beveridge, 2004, p. 27). This was the beginning of the principle of immunisation with attenuated pathogens.

In summary, science is a human activity that thrives under the conditions of curiosity, preparation, and imagination and is considered to be a very interdisciplinary and collaborative endeavour. Diverse educational and social backgrounds provide the necessary building materials to explore new ideas, collaborate with peers, and be curious about the natural world. In addition, it takes a prepared mind to identify the unexpected when watching the expected.

## Colonial Legacy and Contemporary Science Education in India

There is abundant evidence that science and technological fields of study were interwoven with other institutions of society in precolonial India. These include examples from the medical field (e.g. the indigenous method of inoculation against smallpox in 18th century India, also known as tikah), mining and metallurgy (e.g. production of Indian steel or Wootz), and additional fields such as trigonometry and technology (Verma, 2004).

### *Colonial Legacy*

The advent of British colonialism in India led to scientific exploration but only in order to accelerate the expansion of British imperialism. Scholars have documented the nature of science and science education that was promoted and perpetuated during British rule in India. What might be called 'production science' (Alam, 1977, p. 5) was established for profit generation and exploitation of local resources. The new educational policy forced and promoted by British administrators such as Lord Macaulay and Charles Wood, 'were not aimed at making them [Indians] scientist or inventors, but to create a loyal class of Indians, a class of Indian in blood and colour, but English in taste, and opinions, and morals, and intellect' (Sangwan, 1984, p. 179). As an example, the British needed locals to carry out survey and public works projects and thus survey schools and engineering institutions were established (Verma, 2004). The branches of science and technology that were made available to Indians in the educational institutions were not to serve Indians or advance scientific inventions led by Indians but to yield profits for the British Empire. This happened mainly in two ways: (1) India provided a rich diversity of resources that could be tapped for profits and (2) India provided a site for knowledge production through unhindered pursuit of western science. These strategies, on the part of the British, led to an overflow of job seekers in government departments but it also caused a paucity of talent in the fields of science and technology by deliberately neglecting Indian classical science and not having a coherent science and technology policy for the colonised populace, rather one designed to serve the politico-commercial needs of the colonial government. India, therefore, lost on both fronts, 'whereby its own scientific tradition was discarded and the new science remained the privilege of the white with colonial ethos and colour-consciousness eclipsing the evolution and proliferation of Western Science in India' (Verma, 2004, p. 57).

India gained freedom from British colonialism on August 15, 1947 after over 150 years of British rule. The colonial system minimised access to the pre-colonial indigenous educational system and India inherited an education system that was mostly created to train the native Indians to pursue careers as clerks and civil servants. This education system focused on rote memorisation, used print material as the primary tool for education (e.g. textbooks, official documents), high-stakes testing as gatekeeping tools for students at every stage of their K-12 educational experiences. Many efforts have been made by Indian governments since independence to minimise the effects of colonial education. These efforts include setting up various educational commissions to produce policy documents (e.g., National Policy of Education (NPE, 1968); National Curriculum Framework (NCF, 2005)) and enacting new laws (Right to Education (RTE, 2010)) (see Verma and Nargund-Joshi, 2017 for further details on these documents). Despite these policy efforts and curricular/instructional efforts being undertaken by educational agencies such as National Council for Educational Research and Training (NCERT), the majority of the Indian education system continues to be driven by high-stakes testing or an examination system known as the state or central government boards (e.g. Central Board of Secondary Education [CBSE] for public and private schools).

Specifically related to science education, it is well-documented that the ways in which students learn science in school do not align with how scientists participate in the scientific enterprise (Reiff, Harwood, & Phillipson, 2002). This issue is prevalent around the world but is much more visible in post-colonial societies such as India, due to the legacy of colonisations that have set up bureaucratic structures that hinder progress. The much misconceived 'scientific method' presents science as a linear process and the use of the scientific method in textbooks is an invitation to kill creativity by turning science experiments into cookbook labs that follow the inform, verify, and practice model of learning science. Science textbooks often present the scientific method as a set of sequential steps (Jimenez-Aleixandre, Rodriguez, & Duschl, 2000). I believe for too long we have been teaching science as a disconnected sequence of facts that is far removed from the reality of actually practicing science and, for that matter, our students' lives. When we focus on only mastering the content embedded in the science curriculum, we reinforce our cognitive pathways. However, if we were to make this learning collaborative and communicative and provide opportunities for students to engage in public demonstration of their knowledge (e.g. creating and defending original projects), we may educate our students to look for discoveries, significant details and connections that they may not have seen before.

Various researchers such as Reiff et al. (2002) discuss the use of the 'inquiry wheel' to provide an alternate and authentic way to engage students with school science (p. 202). Newer science standards from countries such as the United States (US) represent a significant transition from the previous state standards that were focused on mastering content knowledge only. Specifically, the Next Generation Science Standards (NGSS) focus on students developing 'an in-depth understanding of content and develop key skills—communication, collaboration, inquiry, problem solving, and flexibility—that will serve them throughout their educational and professional lives' (Next Generation Science Standards [NGSS], Lead States, 2013).

## *Contemporary Science Education in India*

These progressive ideas are also manifesting themselves in the science education field in India. The premier institution in India that leads efforts in science education, the Homi Bhabha Centre for Science Education (HBCSE) (http://www.hbcse.tifr.res.in/) has many researchers and scholars working in the field of science education (http://www.hbcse.tifr.res.in/research-development).

Many of the efforts undertaken by the HBCSE (2019a, 2019b) are noteworthy. As an example, a series of books called 'Small Science' (हलका फुलका विज्ञान), developed by HBCSE, allows elementary-aged students to engage with science in innovative ways. Many teachers around the country have adopted 'Small Science' (http://smallscience.hbcse.tifr.res.in/) to facilitate students' skill sets in systematic observation, analysis, and articulation. Vigyan Pratibha is another initiative started by the HBCSE on behalf of the Government of India to nurture talent in Science and Mathematics for students of grades 8–10. This program will be implemented in various central government-run schools such as Kendriya Vidyalayas (KVs), Jawahar Navodaya Vidyalayas (JNVs), and the Atomic Energy Central Schools (AECSs) in the country (http://www.hbcse.tifr.res.in/vigyan-pratibha). The website shares how this program will be implemented by using 'learning units that will be implemented by school teachers…as a part of science circles for interested students. These units will be closely related to the school curricula, but would expose students to dimensions of science and mathematics beyond the textbooks.' It is encouraging to see that institutions such as HBCSE are promoting science education in a progressive and contemporary manner. When the policymaking institutions of the country start planting the seeds, the fruits of the effort will eventually show up.

There are various societal and institutional challenges in implementing progressive science teaching and learning ideas in schools. India has the world's largest educational system, including both public (known as government schools) and private schools (Cheney, Ruzzi, & Muralidharan, 2005). The total enrolment of students at grades 1–5 is 113.5 million and at the secondary level is 30.5 million. This makes the primary level school system the world's second largest system (Verma & Nargund-Joshi, 2017). There is a huge disparity between student performance in Government and Private schools (Kingdon, 2005). The parallel system of government and public schools creates a system of 'haves' and 'have nots' despite the creation of a 25% reservation for the economically weaker sections of society (The Economic Times, 2012). In addition, India also accounts for more than 25% of all out-of-school children worldwide in 2002. Many of these children come from marginalised populations (e.g., working children, children in difficult circumstances) who do not get to participate in formal schooling (World Bank, 2015). In other words, not only are there huge challenges in making formal education accessible to children, providing a quality science education becomes equally challenging.

## What Does It All Mean: Jugaad Thinking and STEM Education and Career Pathways

In this section, I discuss the possibilites of envisaging the intersection between Jugaad thinking and STEM education. Some of the ways to explore these intersections may entail: (1) identifying deep learning skills that arise from engaging in Jugaad thinking and aligning them with STEM learning skills; (2) identifying alternative and inclusive spaces of STEM learning (in addition to formal classrooms) where Jugaad thinking could be integrated; (3) diversifying STEM career pathways to leverage Jugaad thinking with STEM thinking skills.

### *Jugaad Thinking and STEM Learning Skills: An example*

Are there any deep learning skills that emerge from engaging in Jugaad thinking and integrate into STEM formal (and informal) learning spaces? Learning spaces that allow students to be creative, innovative, practice science, solve problems, and contribute to new knowledge by integrating these two ways of being. An example of such a space is a STEAM school project-based experiential learning program run by Maker's Asylum global learning experiences (https://steam.makersasylum.com/school/). Students in this space engage in the process of problem-solving focused on the United Nations (UN) Sustainable Development Goals (SDG). The process includes the steps: Design—Jugaad—Learn—Prototype—Make—Break—Create. The steps shared in the prototyping process show strong alignment with key skills outlined by Next Generation Science Standards (NGSS)—collaboration, communication, problem-solving, flexibility, and inquiry—that will serve students well throughout their lives.

## *Jugaad Thinking and Alternative and Inclusive Spaces of STEM Learning*

Formal spaces of learning (e.g., schools) could be powerful tools of empowerment and social and financial upward mobility. However, formal spaces of learning could also be inherently oppressive and reflect the hegemonic realities of larger society within which they are located (Verma & Puvirajah, 2018). This is especially true for children whose life conditions are shaped by marginalisation low socioeconomic status, and other factors such as caste, gender, and the rural/urban divide. The world of formal education could be very disconnected from the lives of many children in India and may feel very alienating for many of them. In addition, many marginalized children attend government schools where they receive subpar education (Kingdon, 2005). The children are ‘regulated’ into being a subordinate class where their oppressive educational experiences prevent them from having social and intellectual mobility (see Verma & Puvirajah, 2018 for a detailed description of these ideas).

Similarly, many students experience science as a decontextualised list of facts and conclusions to be memorised and regurgitated for tests and examinations. The science education research community has been arguing for a more authentic science learning experience, where students get to engage in real-world problem-solving. We must examine spaces of STEM learning outside of formal schooling for students to participate in genuine scientific inquiry and authentic discourse/s. There is a body of literature on these alternative and inclusive spaces of learning around the world. In the United States, one could look at the informascience.org website to discover projects and research and design evaluation of these alternative learning spaces. One such resources is the Centre for Advancement for Informal Science learning (http://www.informalscience.org/). A similar resource set that could be developed for the Indian context would be creating a community of scholars, researchers, practitioners who come together to explore various alternative and inclusive spaces of STEM learning to broaden participation of students from all walks of life.

Tinkering and Makerspaces are two spaces where these ideas could be explored further. The Merriam-Webster dictionary (2018) defines tinker as, ‘to work in the manner of a tinker, especially to repair, adjust, or work with something in an unskilled or experimental manner’. This aligns very well with Jugaad thinking where people either physically make something work or try to fix a situation. Similarly, Makerspaces are defined as ‘a place in which people with shared interests, especially in computing or technology, can gather to work on projects while sharing ideas, equipment, and knowledge. Makerspaces can be equipped with 3D printers, laser cutters, various milling devices, and more’. The affordances of these places may enable students to voluntarily explore learning opportunities, engage with meaningful projects, and create solutions to an identified problem. The Atal Tinkering Lab (ATL) initiative was started by the Government of India. The ATL program provides grants to school for setting up tinkering labs to create an environment of innovation and creativity amongst Indian students. Students can continue to learn STEM skills that may intersect with Jugaad thinking if such a program could be scaled up and these opportunities are provided to students from marginalised backgrounds.

## *Jugaad Thinking for Diversifying Career Pathways in STEM Fields*

STEM career pathways have traditionally led to careers in engineering, medicine, and/or computer science majors. These pathways and career options need to be expanded to integrate not only STEM content knowledge but also STEM thinking skills and Jugaad thinking. An example could be pursuing a career as a training technicians for the advanced manufacturing field of integrated photonics (NPR, Dec 2018). The skills sets identified in these advance manufacturing positions integrate both STEM and Jugaad thinking. It allows for filling labour gaps in these industries by creating skills-based hiring. While college degrees and formal credentials still are the dominant way to qualify for many jobs, employers in the United States and elsewhere are beginning to embrace micro-credentials (micro-degrees, certificates and other credentials of value). The National Council of Educational Research and Training (NCERT) is introducing vocational training into the regular curriculum for classes IX to XII (http://ncert.nic.in/vocational.html). Some of the fields listed under the vocational training curriculum fall into STEM fields (e.g. automobile service technician, horticulture, and telecommunications).

Earlier, we discussed the idea of seeking patents, copyrights, and trademarks for the indigenous products that exist in the third space (Frenkel, 2008). STEM disciplines also provide affordances to engage in entrepreneurship and create Indian indigenous products. Indian entrepreneurship has been demonstrated around the world (e.g. silicon valley, London, East African, and other places). The start-up ecosystem is taking off in India and it is estimated that there will be 11,000 start-ups by 2020 compared to 4700 in 2016. With a thriving economy and a youthful population, fresh school-leavers and graduates could either join the workforce or become entrepreneurs. The much-discussed demographic dividend will only give us results if we resolve the issue of uneducated, undereducated, and underemployed youth. We will need to embrace our indigenous ways of thinking including Jugaad thinking and successfully integrate it into our education system to be provide inclusive education to ALL children, and harness young India's potential.

## Final Thoughts

The title of this book chapter, 'Jugaad thinking: Contextualised Innovative thinking in India through Science, Technology, Engineering, and Mathematics (STEM) education?' introduced the term 'contextualised innovative thinking'. I would like to claim this term as the closest anglicised translation of the word Hindi word *Jugaad in the context of STEM education*. I argue that it captures the spirit of Jugaad thinking and honours the many STEM focused localised, organic, scalable solutions that have been produced to solve some persistent problems in Indian society. I urge all of us to not only embrace this thinking but also to integrate it into STEM teaching and learning to create and preserve inclusive spaces of learning for ALL Indian children.

## References


Agrawal, A. (2018). *Indian innovators: 20 brilliant thinkers who are changing India*. Mumbai, India: Jaico Publishing House.

Alam, A. M. (1977). Imperialism and science. *Social Scientist, 65*(5), 3–15.

Beveridge, W. I. B. (2004). *The art of scientific investigation*. Caldwell, NJ: Blackburn Press.

Bhabha, H. K. (2012). *The location of culture*. London: Routledge.

Bryson, B., & Roberts, W. (2003). *A short history of nearly everything*. New York: Broadway Books.

Chalmers, A. F. (2013). *What is this thing called science?* (4th ed.). St Lucia, QLD: University of Queensland Press.

Cheney, G. R., Ruzzi, B. B., & Muralidharan, K. (2005). *A profile of the Indian education system.* Prepared for the New Commission on the Skills of the American Workforce.

Dabholkar, V., & Krishnan, R. T. (2013). *8 Steps to innovation: Going from Jugaad to excellence*. Bangalore: Collins Business.

Frenkel, M. (2008). The multinational corporation as a third space: Rethinking international management discourse on knowledge transfer through Homi Bhabha. *Academy of Management Review, 33*(4), 924–942.

Homi Bhabha Center for Science Education. (2019a). *Research and development.* Retrieved from http://www.hbcse.tifr.res.in/research-development.

Homi Bhabha Center for Science Education. (2019b). *Small science.* Retrieved from http://smallscience.hbcse.tifr.res.in/.

Jimenez-Aleixandre, M. P., Rodriguez, A. B., & Duschl, R. A. (2000). "Doing the lesson" or "Doing science": Argument in high school genetics. *Science Education, 84*(6), 757–792.

Joseph, M. (2018, August 18). *'Jugaad', India's most overrated idea.* Retrieved from https://www.livemint.com/Leisure/2c3sntdHfJ8Py2tWxEqgcN/Jugaad-Indias-most-overrated-idea.html.

Kingdon, G. (2005, October). Private and public schooling: The Indian experience. In *Proceedings of Mobilizing the Private Sector for Public Education Conference*. *Co-sponsored by the World Bank Kennedy School of Government* (pp. 5–6), Cambridge, MA: Harvard University.

Kuhn, T. S. (2012). *The structure of scientific revolutions* (4th ed.). Chicago: University of Chicago Press.

Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: Press.

Ministry of Human Resource Development. (1968). *Ministry of Human Resource Development: National policy of education 1968*. New Delhi, India: Government of India.

Ministry of Human Resource Development. (2010). *Right to education act.* Retrieved from https://www.mhrd.gov.in/rte.

Mitra, S. (2017). Realising the demographic dividend: Policies to achieve inclusive growth in India. *Journal of Development Studies, 53*(8), 1323–1324.

National Council of Educational Research and Teaching. (2005). *National curriculum framework.* Retrieved from http://www.ncert.nic.in/rightside/links/pdf/framework/english/nf2005.pdf.

Nelson, D. (2018). *Jugaad Yatra: Exploring the India art of problem solving*. New Delhi, India: Aleph book company.

Pansera, M., & Owen, R. (2014). Eco-innovation at the "bottom of the pyramid". In D. A. Vazquez-Brust, J. Sarkis, & J. J. Cordiero (Eds.), *Collaboration for sustainability and innovation: A role for sustainability driven by the global south?* (pp. 293–313). Dordrecht: Springer.

Radjou, N., Prabhu, J., & Ahuja, S. (2012). *Jugaad innovation: A frugal and flexible approach to innovation for the 21st century*. India: Penguin Random House.

Reiff, R., Harwood, W. S., & Phillipson, T. (2002). A scientific method based upon research scientists' conceptions of scientific inquiry. In *Proceedings of the Annual International Conference of the Association for the Education of Teachers in Science (Charlotte, NC, January 10–13, 2002)*. Retrieved from https://eric.ed.gov/?id=ED465618.

RTE Quota (2012). *The Economic Times*. retrieved from https://economictimes.indiatimes.com/opinion/et-commentary/25-rte-quota-getting-the-poor-into-private-schools/articleshow/13877545.cms.

Sangwan, S. (1984). Science policy and the East India Company in India. In A. Rahman (Ed.), *Science and technology in Indian culture—A historical perspective* (pp. 171–188). National Institute of Science Technology and Development Studies.

Shashtri, P. (2018, July 29). Book review: Dean Nelson's 'Jugaad Yatra: Exploring the Indian art of problem solving'. *The Financial Express.* Retrieved from https://www.financialexpress.com/lifestyle/book-review-dean-nelsons-jugaad-yatra-exploring-the-indian-art-of-problem-solving/1261846/.

Tinker. (2018). Merriam-Webster Dictionary. Retrieved from https://www.merriam-webster.com/dictionary/tinker.

Verma, G. (2004). Colonial and post-colonial science in India: Re-enacting and replaying similar themes in the US. In N. K. Mutua & B. B. Swadener (Eds.), *Decolonizing research in cross-cultural contexts: Critical personal narratives* (pp. 53–68). Albany, NY: State University of New York Press.

Verma, G., & Nargund-Joshi, V. (2017). Educational rights of a girl child in India: Examining intersections between right to education act and national curricular framework In E. Brown & G. Zong (Eds.), *International advances in education: Global initiatives for equity and social justice information (Gender Equity)* (Vol. 10, pp. 85–104). Charlotte, NC: Information Age Publishing.

Verma, G., & Puvirajah, A. (2018). Examining the mediation of power in informal environments: Considerations and Constraints. In K. Tobin & L. Bryan (Eds.), *Critical issues and bold visions for science education: The road ahead* (pp. 187–202). The Netherlands: Sense Publishers.

World Bank (2015). *Educating India's Children.* Retrieved from http://www.worldbank.org/en/country/india/brief/educating-india-children.