Rekha Koul · Geeta Verma ·
Vanashri Nargund-Joshi *Editors*

Science Education in India

Philosophical, Historical, and Contemporary Conversations

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Foreword

It gives me much pleasure to write the foreword to this much-awaited book in the field of science education.

This book has a broad sweep that goes from philosophy and history of education to school science and teacher training, matters related to inclusivity, and indigenous knowledge and innovation. It also includes material on technology, gender, community, and culture issues, and topics related to localized contexts.

The authors of this book, who are from different continents of Africa, America, Asia, and Australia, bring their experience gained in different cultural and political systems to analyze these issues. I believe this is the first book of its kind, and so it will become an important resource for furthering scholarly conversations among educators.

This book is written for researchers and educators. Although its focus is India, its lessons will have value in other international science education contexts. We live in the age of machines which makes science education particularly important for skilling of the workforce, with lessons that have international relevance. The contents of this book should also be valuable to policymakers.

India, the second most populated country in the world, has the largest number of young people under the age of the thirty, and in 2020, the median individual in India will be 29 years, making it the youngest country in the world. Educating this large body of youth in science and computer skills has become a major concern for the Indian Government, requiring consideration of the broader issues raised in the book.

Information about science education in India is scarce both nationally and internationally. I commend the co-editors, who are visionary educational researchers, for recognizing the need for the book and coming together to make it happen.

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Preface

Education is a complex endeavor in itself. The complexity is further increased when a nation such as India attempts to create impactful educational opportunities for millions of children with the premise that education is a basic human right that needs to be fulfilled per the constitution of the country. However, in India, a long history of colonialism, diversity of cultures and languages, and a large population (approximately 276 million people) still living under the official poverty make this endeavor extremely challenging, if not impossible.

India has about 260 million children enrolled in over more than 1.5 million schools, and approximately 80 million teachers engage in educating such a large number of children (School Education in India, 2014–2015). India also has world's youngest populations—scholars coined the term, "demographic"—"demographic dividend" to describe this phenomenon (Mehrotra 2015). Demographic dividend could be understood as the economic potential that can be reaped from shifts in a population's age structure (when the working-age population [15–64 years] is larger than the nonworking share of population [under the age of 14 and 65 years and older]). Demographic dividend creates a potential for the younger population in India to contribute to the future of the country. However, in order to maximize this potential, various educational, economic, and societal structures and policies need to be available to allow the youth to participate. In the context of educational opportunities, the potential of demographic dividend is under realized in many ways in India. One such indicator is the 2009 results of the Programme for International Student Assessment (PISA) study organized by the Organisation for Economic Co-operation and Development (OECD 2009). India was ranked 72nd out of 73 participating countries in the 2009 PISA study. Unfortunately, it is not possible to document the growth trends since 2009, as India has not participated in international tests after 2009. We acknowledge the existing criticism of PISA tests and the many reasons why countries may choose not to participate in it. However, other indicators of educational benchmarking (including out of school children) indicate similar outcomes pointing to access, quality, and equity issues in educational opportunities for children in India (Borkotoky & Unisa 2013; Kingdon 2007).

Within the larger educational conversation lies the topic of Science, Technology, Engineering, and Mathematics (STEM) education. Scientific administrators at the National Science Foundation (NSF) introduced the STEM acronym in 2001. NSF is one of the United States (US) government agencies that support fundamental research and education in all nonmedical fields of science and engineering. The term is not without controversy as it may have a different meaning for different people. According to one definition, "STEM education is an interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world lessons as students apply science, technology, engineering, and mathematics in contexts that make connections between school, community, work, and the global enterprise enabling the development of STEM literacy and with it the ability to compete in the new economy" (Gerlach 2012). In this definition, the STEM acronym blurs the boundaries between STEM education and STEM workforce by integrating the ideas of global economy, competition, community, and work. In other words, the silos approach to studies (e.g., science, mathematics education) is being deconstructed and new ways of teaching and learning these areas of study are emerging. The STEM acronym has become widely accepted around the world, and it collectively refers to the areas of study listed in the acronym as well as the implications of these fields of study for global competitiveness in terms of preparing students, teachers, practitioners, and workforce in the STEM fields. Many scholars argue for integrating liberal arts and changing the acronym to Science, Technology, Engineering, Arts, and Mathematics (STEAM) education.

This book focuses on the field of science education in India within the larger context of STEM education. A few chapters specifically speak about science education, while the focus of others blurs within the larger field of STEM education. As an example, authors' (Gupta, Koul et al., and Verma) work lies in a larger conversation of STEM education. Therefore, we wanted to specify that the contributing authors in this book use the terms science education and STEM education interchangeably.

Science Education Policies in India

Education systems in India are placing increasing emphasis on Science and Mathematics; however, neither engineering nor technology is a part of curricular or pedagogical initiatives (National Policy on Education 2016). In addition, there is a lack of infrastructure (access to basic infrastructure, scientific equipment, and updated curricula) and human resources [shortage of quality teachers to improved science and mathematics education in India (Sarangapani 2017)]. To further exacerbate the situation, red tape in administration and academic initiatives and unceremonious attitudes of stakeholders contribute to the declining quality standards of the Indian education system (National Policy on Education 2016). In terms of science education specifically, it is well documented that students lack opportunities to engage in educational experiences that promote critical thinking, inquiry-based learning, and hands-on/minds-on learning. This leads to a large number of students dropping out from science education at the high school level. The vacuum in meaningful, engaging, and authentic science learning experiences is further worsened by a mushrooming phenomenon of after-school coaching institutes and private tuition providers that prepare students to succeed in high-stakes examinations. The existence of these parallel and supplementary educational providers is a clear indicator of poor and limited instructional and pedagogical practices in India. Despite proposing and implementing various policies, overall science and mathematics competencies of Indian students at various levels of schooling are reported to be well below OECD standards (World Bank Report 2018).

The national educational policy in India was established soon after independence in 1947. National Policy on Education (NPE) was first formulated in 1968 and later modified in 1986 and 1992. In these policy documents, it is clearly recognized that education that focuses on equity, accessibility, and quality is a precondition for development. The latest National Policy on Education (NPE 2016) confirms the previous stance of education being the most important tool for social, economic, and cultural transformation. NPE (2016) lays a great deal of emphases on innovation, critical thinking, and skill development by focusing on four essential components, i.e., building values, awareness, knowledge, and skills. These building blocks are critical for enabling citizens to develop skills and competencies to contribute to the nation's well-being, strengthening democracy, and fostering social cohesion (NPE 2016). India's Scientific Policy Resolution (SPR) was developed parallelly with NPE in 1958 and also resolves to foster, promote, and sustain the cultivation of science and scientific research in all aspects. This was followed by the Technology Policy Statement (TPS 1983)—focusing on achieving technological competence and self-reliance. Science, Technology and Innovation Policy (2013) focused on the concept of demographic dividend as well as sustainable and inclusive development. This latest policy statement integrated national interest programs as well as created innovation ecosystems for research and development (R&D). In other words, science, technology, and innovation have been identified as the drivers for India's faster, sustainable, and inclusive growth (Science, Technology and Innovation Policy 2013).

Science School Programs in India

The policies developed by the Indian governments post-independence focuses on fostering scientific temperament, skills for application of science, and making STEM careers attractive among school students. In addition to science teaching in preK–12 settings, we briefly want to discuss a few programs that have been established to achieve these policy goals as well as address equity, accessibility, and quality conversations.

Connected Learning Initiative (CLIx): It is the first initiative undertaken by the Tata Trusts in collaboration with Massachusetts Institute of Technology (MIT). It is a bold and innovative effort that aims to improve the professional and academic prospects of high school students from underserved communities in India. It supplements the high school curriculum in key areas, including digital literacy, mathematics, science subjects as listed in the curricular documents (biology, chemistry, and physics). CLIx is currently being implemented in four states—Chhattisgarh, Mizoram, Rajasthan, and Telangana, where it is available to approximately 1,11,000 high school students and some 4500 teachers in over 1100 government schools. CLIx was selected out of 143 entries from 79 countries worldwide for the 2017 edition of the UNESCO Prize for the use of ICTs in education (http://www.tiss.edu/view/11/connected-learning-initiatives-clix/).

Atal Tinkering Laboratories (ATL): With a vision to cultivate one million children in India as Neoteric Innovators, Atal Innovation Mission (https://aim.gov.in/atal-tinkering-labs.php) is establishing Atal Tinkering Laboratories (ATLs) in schools across India. The objective of this scheme is to foster curiosity, creativity, and imagination in young minds and inculcate skills such as design mindset, computational thinking, adaptive learning, physical computing. ATL provides a workspace where children can give shape to their innovative ideas through hands-on activities with tools and equipment to understand the concepts of STEM. Funding under this scheme is managed by the government, local body, or private trusts/society, and approximately 2443 schools across the country have been selected to establish ATL.

Innovation in Science Pursuit for Inspired Research (INSPIRE): Department of Science and Technology (DST) developed INSPIRE, an innovative program in 2008 with long-term foresight for attracting young talent to the excitements of a creative quest of science as a career option and building the required critical human resource pool for strengthening and expanding the Science and Technology system and Research and Development base in the country. INSPIRE Award targets approximately two hundred thousand school children every year in the age group of 10–15 years, i.e., from 6 to 10th standards, and provide an opportunity to showcase imagination, innovation, and creativity. A total of 800 science camps have been held covering around a similar number of students in the age group of 16–17 years. Various other initiatives have also been taken for students in tertiary education.

National Children's Science Congress (NCSC): The seeds of the program for children's science congress (CSC) were started as small research activities at microlevel by a nongovernmental organization (NGO) and was later adopted by DST for carrying out national-level activities. There was a need for large-scale activities for developing science awareness among the broader population. Therefore, this program was launched nationwide in 1993, under the name National Children's Science Congress (NCSC). The expectation of the program was to generate scientific temperament among the teachers and students as well as among other stakeholders of the society. NCSC program has been successfully conducted for the last 23 years. NCSC is mandated to communicate science and technology to broader population. The council's program aims at building capacity for informed decision-making in the community. NCSC encourages research in the areas of Science and Technology (S&T) communication, training of communicators, development of books, manuals, posters, exhibitions, films, radio programs, and television programs. It recognizes outstanding efforts through awards and incentives all over the country. About 650 projects from all over the country enter the national-level project directory every year (National Children's Science Congress 2018).

The Initiative for Research and Innovation in Science (IRIS): This program was initiated in 2006 with the intention to popularize STEM fields and the spirit of innovation among students from class 5 to class 12. It recognizes and rewards outstanding young innovators and provides a platform for them. IRIS workshops are conducted to reach out to schools across the country, after which young students submit research-based STEM projects, which are evaluated, keeping in mind the level of innovation and scientific robustness. IRIS is an outstanding example of public–private partnership initiated by Intel Technology India Private Ltd. (Intel) with DST and the Indo-US Science & Technology Forum (IRIS National Science Fair 2017). One of the challenges faced by this program is the lack of a culture of research and innovation in the school systems and inadequate capacity of teachers to mentor students to meet the international standards.

Science Express: The Science Express is a mobile scientific exhibition for children mounted on a train, which travels across India. Department of Science and Technology (DST) launched the project in New Delhi in 2007. Although open to all, the project primarily targets school students and teachers. As of 2017, the train has had nine phases and has showcased exhibitions on three themes. The first four phases from 2007 to 2011 were called "Science Express" and were focused on micro- and macro-cosmos. The next three phases from 2012 to 2014 remodeled the exhibits as "Biodiversity Special". The eighth and ninth phases from 2015 to 2017 were redesigned to focus on "Climate Change". The exhibition while in its eighth phase had traveled for 1,41,800 kilometers, halted at 455 stations, and reached out to more than 1.56 crore people (Science Express 2019).

Science Exhibition: Since 1971, National Council of Education Research and Training (NCERT) organizes national-level science exhibition every year where children showcase their talents in science and mathematics and its applications to various aspects of everyday life. This is done with a view to encourage, popularize, and inculcate scientific temper among the children. NCERT organizes the exhibition in two phases to ensure the widest possible participation and involvement of students and teachers in the program. In the first phase, exhibitions are held in each and every state and various union territories. This first phase is known as State Level Science, Mathematics and Environment Exhibition (SLSMEE). All participating states and union territories forward their selected entries to NCERT for consideration for participation in the national exhibition. The second phase is held at national level every year by NCERT in a state/UT, on a rotational basis. The exhibits for display in this national exhibition are selected at NCERT on the basis of a notified criterion (Science Exhibition 2017).

Current Health of Education and Science Education in India

India has decreased its spending on education from 4.4% of gross domestic product (GDP) in 1991 to around 3.71% in 2017. Currently, India spends around 2.7% of its gross domestic product (GDP) on education (NPE 2016) as against recommended 6% of GDP recommended by Kothari Commission. Comparing India to other BRICS nations (Brazil, Russia, China, and South Africa), it has spent the least among these peer nations. In terms of expenditure on Research and Development (R&D), India spends approximately 0.88% of its GDP toward R&D (Research and Development Statistics, 2011–2012). In addition, the limited contribution of private sector (2% of GDP) to R&D as a percentage of GDP drags behind the preference of Government of India (GDP in Science Research, November 27, 2014).

We share this data to contextualize and situate the country's spending on education (both pre-k-12 and higher education). The aspiration of the Science, Technology and Innovation Policy (2013) to position India in the top five global scientific powers by 2020 is a goal worth seeking. However, for these policy goals to become reality (and ensure sustainable and inclusive development) based on S&T knowledge fields will require us to have a critical examination of our preK–12 education system.

The current prime minister of India has indicated that science, technology, and innovation are the keys to progress and prosperity in India. The various initiatives listed above are meant to identify the brightest and best science talent among school students as well as create effective mechanisms to reduce the drudgery in science learning through intentional interventions in the Science and Technology (S&T) fields by 2022 (the 75th year of Indian independence) (Science, technology, innovation keys to India's progress: Modi, July 19, 2017). In addition, there is an attempt to transform 20 Indian universities into world-class institutions by infusing a package of Rs. 100 billion (approximately $2 billion).

Government of India is trying to introduce social constructivist teaching (Vygotsky 1997) by spending a major part of the research budget on STEM programs for school students. There is no doubt that many programs are implemented at mass scale like NCSC, Science Express, and INSPIRE to enhance the awareness of science and STEM fields and prospective career options. However, there are some limitations when programs are implemented a result of policy goals, and they are mostly implemented in a top-down manner. In addition, designing programs using a competition model allows for the selection of a few percentages of students. As an example, only top 1% students in INSPIRE program who score high in the 10th board exams are selected. This process leaves behind students who may have an aptitude (and interest) in science and STEM fields but who do not perform well on national/state tests or who do not win these competitions. The same group of students seem to be selected for various earmarked science competitions based on their performance in these examinations. This may dampen the participation of students who may excel on other measures of assessment —this process mainly lowers access and equality for disadvantaged students and may also act as a negative motivation.

It appears that these challenges are insurmountable. However, we argue that in order to overcome these challenges, we need to draw upon bold visions that push our thinking and solve the unequivocally complex challenges faced by the Indian education system specifically in the STEM education fields. This book adds a critical voice and is an attempt to inform policy and innovation conversations related to STEM education. As mentioned earlier, this book focuses on science/STEM education in India—an important and integral area of study in schools and post-secondary education. This book is divided into four sections: I) History and Philosophy Conversations; II) School Science and Science Teacher Education; III) Inclusivity and Access in Science Education; and IV) Indigenous Knowledge, Technology, and Innovation. We have organized this book to discuss the contemporary conversations (e.g., Koul et al. chapter on STEM through a Makerspace Approach or Nargund-Joshi's chapter on Science Teachers' Orientations) as well as push our thinking in other areas (e.g., Gupta's chapter on Technology in Science Education, Honwad's chapter on Community-Engaged Science Education and Verma's chapter on *Jugaad Innovations* and *Jugaad Thinking*) in STEM education. This is another one of the bold visions we propose in this book where content area silos are broken and alternative and inclusive spaces (e.g., maker spaces, tinkering spaces, and coding academies) of STEM learning coexist, supplement, or replace existing spaces of science learning. We argue that thinking about these ideas may allow us to engage in conversations that will create inclusive spaces of science learning for all students.

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References

ATAL Tinkering Laboratories—Innovation Challenge (2018). Retrieved from http://niti.gov.in/content/atal-tinkering-laboratories-%E2%80%93-innovation-challenge.

Borkotoky, K., & Unisa, S. (2013). Educational progress in India in the context of out-of-school children. *International Journal of Social Sciences, 2* (5), 6–14.

CLIx Connected Learning Initiative (2018). *(*http://www.tiss.edu/view/11/connected-learning-initiatives-clix/*)*

GDP in Science Research, (Nov 27, 2014). Retrieved from http://pib.nic.in/newsite/PrintRelease.aspx?relid=112011

Gerlach, J. (2014). STEM: Defying a Simple Definition. NSTA WebNews Digest - NSTA Reports 2012 [February 10]; Retrieved from: http://www.nsta.org/publications/news/story.aspx?id=59305

INSPIRE Awards-MANAK. (2018). Retrieved from http://nif.org.in/inspire-awards.

IRIS National Science Fair. (2018). Retrieved from http://www.irisnationalfair.org/.

Mehrotra, S. (2015): *Realising the demographic dividend—policies to achieve inclusive growth in India*, Springer.

Kingdon, G. G. (2007). The progress of school education in India. *Oxford Review of Economic Policy*, *23*(2), 168–195.

National Children Science Congress. (2018). Retrieved Date from http://www.ncsc.co.in/.

National Policy on Education. (2016). Retrieved from http://www.nuepa.org/New/download/NEP2016/ReportNEP.pdf.

OECD. *Education at a Glance 2009*: OECD Publishing.

Research and Development Statistics. (2011–12). Retrieved from http://www.nstmisdst.org/PDF/FINALRnDStatisticsataGlance2011121.pdf.

Sarangapani, P. M. (2017). Three challenges facing indian school science education.

School Education in India. (2014–15). Retrieved from http://www.dise.in/Downloads/Publications/Documents/U-DISE-SchoolEducationInIndia-2014-15.pdf

Science Exhibition. (2018). Retrieved from http://www.ncert.nic.in/programmes/science_exibition/index_science.html.

Science Express. (2018). Retrieved from http://www.sciencexpress.in/.

Science, Technology and Innovation Policy (2013). Retrieved from http://www.dst.gov.in/sites/default/files/STI%20Policy%202013-English.pdf.

Science, technology, innovation keys to India's progress: Modi. (July 19, 2017). Retrieved from https://www.deccanchronicle.com/nation/current-affairs/190717/science-technology-innovation-keys-to-indias-progress-modi.html

Vygotsky, L. S. (1997). *The collected works of LS Vygotsky: Problems of the theory and history of psychology* (Vol. 3). Springer Science & Business Media.

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Editors and Contributors

About the Editors

Rekha Koul is Dean of International Humanities and an Associate Professor at the School of Education, Curtin University, Perth, Australia. She has nearly three decades of teaching and research experience. Her expertise lies in the development, refinement and validation of questionnaires; investigations of the effects of classroom environments on student outcomes; evaluation of educational programs; teacher action research aimed at improving their environments, and curriculum evaluation. She has successfully secured many local, national and international research grants. Her publication record includes one authored book, four edited books, four book chapters and many journal articles published in peer-reviewed journals. She has delivered invited keynote addresses and also conducts teacher professional learning workshops.

Geeta Verma, Ph.D. is an Associate Professor of science education at the University of Colorado Denver. Her research interest focuses on (in) equity issues in science education and she focuses on creating equitable, imaginative, and innovative Science, Technology, Engineering, and Mathematics (STEM) learning environments. She has secured grants from National Science Foundation (NSF) to support her work. Geeta serves as the incoming co editor-in-chief for the *Journal of Science Teacher Education as well* as well as an associate editor for the *Journal of Research in Science Teaching*.

Vanashri Nargund-Joshi, Ph.D. is an Associate Professor of Elementary/Secondary education and Biology at New Jersey City University. Her research interest focuses on teacher education and more specifically on Pedagogical Content Knowledge (PCK) development of STEM teachers. She works as a Lead at New Jersey Liberty STEM Alliance Ecosystem. Liberty STEM Alliance ecosystem pathways for improving STEM literacy, ensuring a strong workforce and global competitiveness for all. It is an important means to support diversity, equity, and inclusion in a thriving STEM workforce. Vanashri also serves as an associate editor for the Journal of Science *Teacher Education*.

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Garima Bansal is Assistant Professor in the Department of Education at Lady Irwin College, University of Delhi, India. Her research interests include educational assessment, science and mathematics education, multilingualism in science, science classroom discourse and teacher education. She has been awarded several international awards by the American Evaluation Association, International Association of Educational Assessment and British Educational Research Association. She has published widely in national and international journals.

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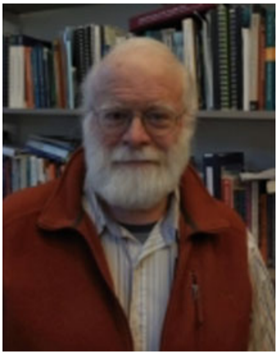
She is associated with multiple national and international organizations like EUMIND, Saveus, ISA, NCO and IAYP to make a difference in teaching as well as part of her professional development. She also undertakes environmental conservation and awareness projects.



Robert Eckert 'Robin' is Professor of environmental conservation and sustainability at the University of New Hampshire. He has co-taught courses in sustainable living and systems thinking for sustainable living for 18 years at UNH. His interests have included investigating air pollution impacts on forest vegetation, biodiversity in New Hampshire streams and invasive plant species. His recent activities focus on innovative cooperation among farmers at the local scale and the role of indigenous knowledge in the management of national park land.

Dr. Adit Gupta is Director of Model Institute of Education and Research, Jammu, and is also Professor and Principal at the MIER College of Education, Jammu. He has a Ph.D. in the field of 'learning environments' from Curtin University, Perth, Australia, and a master's degree in psychology and education. He has over 24 years of teaching and professional experience at the school and college levels. Recipient of the prestigious 'Endeavour Executive Award' of the Australian Government in the year 2009 for conducting research in his area of specialization, he was also appointed as 'Endeavour Awards Ambassador' for the year 2016 by the Australian Government and is also 'Adjunct Research Fellow' at Curtin University, Australia.

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Sameer Honwad is Assistant Professor of learning sciences at SUNY Buffalo. His research focuses on building learning communities for environmental sustainability with particular emphasis on environmental decision-making, impact of curriculum on environmental decision-making processes and technology design for learning. He is currently PI on a large National Science Foundation-funded grant and Co-PI on another large National Science Foundation grant.

Erica Jablonski has a doctorate in sociology. She received a master's degree in applied sociology with a concentration in research methods. She has worked in educational research and evaluation for over 10 years, more than 7 of which were devoted to science education specifically. For the Spirals Project, she conducts research activities, as well as organizing and managing project data.

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Elaine Marhefka has master's degree in elementary education with a bachelor degree in earth science teaching and is currently working toward a Doctorate of Philosophy of education, with a specialization in curriculum and instruction. She loves teaching, previously at the elementary level and currently Adjunct Professor in the Education Department at the University of New Hampshire and Instructor of her self-created outdoor community-based science program for preschool-aged learners and their families. Most recently, she contributed to the Spirals and Schoolyard SITES research projects with the University of New Hampshire, promotingcommunity-based and place-based science instruction, as a Research Assistant and community volunteer, respectively.

Michael Middleton is Klara and Larry Silverstein Dean of the School of Education at Hunter College in the City University of New York. His scholarship focuses on the role of cultural and classroom context on achievement motivation. His scholarly work includes the book *Motivation to Learn: Transforming Classroom Culture to Support Student Achievement.*

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Dr. Neeraja Raghavan is Teacher Educator and Founder Director of Thinking Teacher (www.thinkingteacher.in). She is Author of several books, the most recent being Teaching Tales, Learning Trails (co-authored with Vineeta Sood and Kamala Anilkumar, Notion Press 2018) and The Reflective Teacher (Contributing Editor Vineeta Sood, Orient Blackswan, 2015).

Umesh Ramnarain is Professor in science education at the University of Johannesburg, South Africa. His research is on inquiry-based science education, with a particular focus on its uptake in South African classrooms. The importance of his work has been recognized internationally through publications in top tier journals such as *Journal of Research in Science Teaching, International Journal of Science Education, Research in Education, Teaching and Teacher Education* and *Chemistry Education Research and Practice*.

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Aniket Sule Faculty Member of Homi Bhabha Centre for Science Education (HBCSE), TIFR, Mumbai, India. He has been involved in planning and execution of numerous talent nurture programmes in India for more than a decade. He is also Secretary General of International Olympiad on Astronomy and Astrophysics (IOAA).

Madhavi Tandon has over 25 years of experience in teaching, education administration and education management on three continents. She is currently heading a start-up in Colorado that is focused on widening the notion of achievement for minoritized students using technology.

Claes Thelemarck As Extension Field Specialist, Claes Thelemarck works to engage youth, informal educators and 4-H volunteers in STEM learning. He is responsible for developing inquiry-based STEM activities and curriculum, training 4-H volunteers, teachers and out-of-school-time professionals and running STEM and Maker-based events. He provides support for 4-H volunteer leaders and 4-H clubs throughout Carroll County. He develops and helps run 4-H STEM and Maker activities and events and runs a 4-H Makers club in Carroll County and New Hampshire.

Ruth Varner is Professor of biogeochemistry in the Earth Systems Research Center of the Institute for the Study of Earth, Oceans, and Space and in the Department of Earth Sciences. She is also Director of the Joan and James Leitzel Center for Mathematics, Science, and Engineering Education at the University of New Hampshire.

History and Philosophy Conversations

History of Science in India: Focus on Pre-vedic and Vedic Times

Madhavi Tandon

Abstract This chapter will assess the nature of science in Ancient India, focusing mainly upon the period of the Indus Valley Civilisation and the Vedic times. The use and application of science in Ancient India has always been a debated and controversial topic; therefore, in order to present information without the bias of ongoing and old controversies, internal evidence from the Vedic texts is stated and laid out for the reader to interpret. To help readers understand the evolution of science in India, this chapter will investigate the application and use of sciences in the four Vedas and the Smrutis and will relate it to modern education by using frameworks such as curriculum, pedagogy and assessments. Additionally, this chapter will also provide some background information about the education system prevalent in Ancient India and in the subsequent periods that were influenced by Buddhism, Islam and British colonisation.

Introduction

In their description of the nature of science, McComas and Olson (1998) state that four disciplines help to provide insights into the nature of science—philosophy, history, sociology and psychology of science. The nature of science cannot be understood without a study of the prevalent social, economic and political contexts and a historical review of science helps to establish it as a social and cultural tradition that has global implications regarding generation and dissemination of knowledge. Another advantage of adopting a historical approach to science is the ability to raise questions usually not addressed in textbooks, such as the role of religion, caste, language, wars, invasions and colonialism in the ownership and access of knowledge. Although inclusion of science education as a formal subject in school curriculum in the West is attributed to William Sharp in 1850 at Rugby School in England (Oxford Dictionary, 2017), the existence and application of science and science education

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has existed for centuries prior to the formalised date and this chapter will provide a historical overview from the pre-Vedic period to colonial times in India.

The current framework for teaching science in the United States is based on the Next Generation Science Standards. The core concept is that the key ideas from domains of Physical Science, Life Science, Earth Science, Space Science and Engineering have broad importance within or across multiple Science or Engineering disciplines and should be taught to students within this broader spectrum (Next Generation, 2017). In the United Kingdom, the core aim of the science curriculum is to develop scientific knowledge and conceptual understanding through the specific disciplines of Biology, Chemistry and Physics (U.K. Department of Education, 2015). However, when we discuss the existence of science in ancient times, a definition that is limited to a few modern domains or subjects cannot serve as a relevant framework for further enquiry and I have, therefore, set aside the above definitions of science. While trying to understand science historically, a broader framework is required to be able to make inferences based on available evidence and to relate these to the nature of science as we know it today. Therefore, for the purposes of this chapter, I have conceptualised science as the pursuit and application of knowledge and understanding of the natural and social worlds (Science Council, 2017) and the ability of people to use this knowledge to improve their lives. Therefore, the word science in this chapter, which is grounded in an ancient civilisation, has a broader scope as it includes not only the modern domains defined above but is also extended to other domains that applied the principles of science, such as mathematics and engineering.

Literature and Scope

I have reviewed a large amount of secondary literature on this topic to build a conceptual base. The literature reviewed includes Hindi and English translations of Vedic texts, commentaries on the Vedas by Indologists and linguists published in books and websites, and peer-reviewed articles in academic journals. This chapter is meant to be an introduction to the History of Science in India and is not an exhaustive commentary on the subject. I have synthesised relevant information from various sources for an audience that is trying to understand the roots and nature of science in Ancient India.

This chapter is broadly divided into two main sections, the Indus Valley Civilisation and the Vedic Period. There are various other smaller sub-sections that discuss the education system and schooling in the Vedic, Buddhist, Islamic and British periods and each part deals briefly with a specific historical period starting from 2800 B.C. and ending with colonial India. The chapter contains several words in Sanskrit that I have tried to explain, but not translated, as it is difficult to find equivalent words in English. I have also chosen not to italicise Sanskrit words as it is not a foreign language when we discuss the Vedas, it is the language of the Vedas. Furthermore, the chapter does not provide details about other related aspects of Hinduism, such as the caste system, gender roles, marriage systems and topics that fall outside its scope.

While acknowledging the existence of other pre-historic cultures, some of the earliest documented evidence of human civilisation in the Indian sub-continent originates in research and literature on the Indus Valley Civilisation (IVC), hence, it would be a logical starting point in history to examine the application and use of science by the Indus people.

The Indus Valley Civilisation

This section examines the ways in which science was used by the settlers of the Indus valley. The Indus Valley Civilisation (IVC) was an ancient civilisation along the lower Indus River and the Ghaggar-Hakra River basin in what is currently Pakistan and western India. The civilisation covers the period from 2800 to 1900 B.C. (Kenoyer, 1998; Shinde & Willis, 2014) and in history, this period is known variously as the IVC, Harappan civilisation or the pre-Vedic period as it refers to the era before the Vedas were written. The IVC is one of the earliest known urban societies in South Asia (Kenoyer, 2006), where humans settled in cities, farmed, and also invented a system of writing that has not yet been deciphered (Kanopy, 2016). Over 1000 sites have been excavated to date that includes major cities such as Mohenjodaro, Harappa, Dholavira, Rakhigarhi and smaller urban centres such as Ganeriwala and Kalibangan. Table 1 shows the major archaeological sites that have been excavated over the last century and some of the major findings that indicate an understanding and application of sciences during that period.

Artefacts excavated from the sites narrate a story of the lives of people who lived in the IVC, henceforth referred to as the Indus people. These artefacts, analysed using tools such as carbon dating and translations of ancient texts, provide information and evidences about the food, society, religion, economy and health of the Indus people (Singh, 2009; Siva, 2007) and help us throw light on the sciences used by them, which are briefly described below.

Agriculture

In the present day, agricultural science is defined as the study of science and management of biological systems for the sustainable production of food and fibre (University of Melbourne, 2017). By this definition, the Indus people had made definite progress in agricultural sciences and had cultivated a rich plant life including wheat, barley, peas, sesame, dates, and cotton (Petrie, Bates, Higham & Singh, 2016; Possehl, 2003). Animals essential for agriculture, including zebus, buffaloes, oxen and goats, were domesticated and used in fields or to pull wagons and carts (Kanopy, 2016; Mookerji, 1969; New World Encyclopedia, 2018; Vidale & Frenez,

Table 1 Sites from the Indus Valley Civilisation with major finds

Site/Location/River	Exceptional finds and features	Science used
Harappa/Pakistan/Raavi	Six large granaries in a row grid city	Architecture, Urban & Town Planning, Agriculture
Mohenjodaro/Pakistan/Indus	Great Bath, Granaries	Architecture, Urban & Town Planning, Agriculture
	Bearded Man, Dancing girl in bronze	Sculpting, Textiles, Metallurgy
	Cotton cloth	Textiles and Weaving
Lothal/Gujarat, India	Artificial Dockyard Tiled flooring in houses	Architecture, Urban & Town Planning
	Rice Husk	Agriculture
Chanhudaro/Pakistan/Indus	Lipstick, Perfume flasks, Inkpot	Dyeing, Chemistry
Surkotada/Gujarat	Bones and remains of horse, mongoose, elephant, wolf	Animal Husbandry and Domestication
Kalibangan /Rajasthan/Ghaggar	Black bangles made of terracotta, shell, alabaster, steatite and faience Fire altars and furnaces	Chemistry, Measurement, Firing and Baking
	Ivory comb	Carving
	Copper Buffalo	Smelting and Metallurgy
Dholavira/Gujarat	Water management system Stone reservoir	Resource Conservation and Planning
	Brick lined drains	Sewage Systems-Public Health and Hygiene
Rakhigarhi/Haryana	Fire altars	Measurement, Geometry, Mathematics
	Weights	Mathematics
	Bronze artefacts & statues Copper fish hooks, needles Gold foundry	Metallurgy and Mining
Mehrgarh/Pakistan	Drilled human molars	Dentistry, Pain management

2015). Additionally, the Indus people had succeeded in cultivating enough grains to require storage (Thapar, 1975), thus indicating an approach of communal and social welfare. To sustainably cultivate land and feed the population, Indus people of this era had successfully utilised various aspects of our modern sciences, such as biology, chemistry, animal husbandry and natural resources management.

Architecture

Town planning in the IVC suggests knowledge of urban planning and housing with a high priority on public health and hygiene (New World Encyclopedia, 2018; Thapar, 1975). Some of the features of the excavated cities include protective walls, granaries, warehouses, dockyards and brick platforms. The houses had thick walls covered with mud plaster that allowed the interior to remain cool in summers. Moreover, the houses had no windows that overlooked the main street, probably to keep out the noise and dust but smaller side windows were built to let in light and air (BBC, 2017). Houses were of varying sizes and some had only one room while others had multiple rooms arranged around a courtyard (Thapar, 1975). The source of water for individual houses was wells, and the wastewater, sewage and drainage were guided into covered drains along channels that lined the major streets. Some of the houses had indoor toilets and water storage facilities. Excavations demonstrate that although the houses varied in size, all had access to water and drainage, unlike even modern-day India, thus indicating an egalitarianism in public services (Havell, 1915; Possehl, 2002; Wheeler, 1968).

Fabrication

The bust in Fig. 1, of a male wearing a headband, armband, a brocade fabric covering and neatly combed back hair was excavated from the Mohenjodaro site in Pakistan. This woven garment indicates that the Indus people had learned the process of creating fabric, which involves weaving fibres, from either plants or animals, and processing it into cloth. The jewelled headband and armband indicate that they were not only artistic but had learned to smelt and cast gold and other metals to produce faience, seals, jewellery, statues and sculptures using fine tools (Allchin & Allchin, 1982; Sharma & Sharma, 1996). While copper, bronze, lead, and tin

Fig. 1 Bearded man from Mohenjodaro, National Museum of Karachi

were used in daily life to manufacture tools and objects, the Indus people had also manufactured wagons with two and three wheels and ploughs that were pulled by oxen, thus indicating the application of sciences such as chemistry, metallurgy and engineering.

Weights and Measures

The Indus people had made significant progress in measuring length and mass. A uniform system of weights and extremely precise measures had been developed with the smallest division recorded being 1.704 mm marked on an ivory scale (Singh, 2008). Every brick used in construction was fabricated in a ratio of 4:2:1 to ensure standardisation. A standardised system of weights was also used consisting of 0.05, 0.1, 0.2, 0.5, 1, 2, 5, 10, 20, 50, 100, 200 and 500 units with each unit weighing approximately 28 grams. The weights were manufactured in basic geometrical shapes of hexahedra, cones, barrels and cylinders (Singh, 2009).

Medicine

Recent excavations in the regions of Baluchistan, Pakistan, in the year 2000 indicate that Indus people had access to dentistry. Scientists have discovered intact molars that had perfectly round drilled holes and concentric grooves; the holes were 2.5 mm in diameter and Cucina and Petrone (2001) state that the evidence is indicative of dental work that could have been done to treat tooth decay and reduce pain.

Towards 1900 B.C. the IVC began to collapse and people started to abandon its cities. The reasons for the decline and collapse of the IVC are still contested, with two theories being most popular: the Aryan invasion theory and the theory of climate change. In recent years, the Aryan invasion theory has been rejected by scholars for lack of evidence and the theory of climate change for the decline of the IVC is gaining wider acceptance (Danino, 2006; Frawley, 1994; Prasanna, 2012). If we accept the latter reason, then ancient India appears as a continuous and consistent indigenous development of civilisation in the ancient world (Frawley, 1994). According to the climate change theory, the Saraswati River began to dry up and was unable to sustain its dependent population and gradually the Indus people started relocating eastwards and away from the drying Saraswati while maintaining all the main elements of their culture (Erdosy, 1995; Rao, 1991; Shaffer & Lichtenstein, 1995). The IVC was followed by the Vedic Period, an era when the four Vedas, the oldest and sacred texts of Hinduism were being composed and written. The Vedic Period is placed circa 1500 B.C. and ended around 500 B.C. according to most scholars.

The Vedic Period

The Vedic civilisation, geographically located in the north and northwest regions of present day India, is one of the early human societies, and the Vedic texts, described in Table 2, provide a documentation of its religious, social and economic evolutions. Despite over two centuries of research on Vedic texts by scholars from around the world, only a small proportion of these are available in a reliable peer-reviewed format (Elby, 2014).

Scholarly research indicates that the Rigveda is the earliest Indian text that originated in northern India among tribes of pastoral people who spoke an early form of Sanskrit and practiced Hinduism as a religion (Jamison & Brereton, 2014; Sharma & Sharma, 1996; Staal, 2009; Witzel, 2003). As the IVC collapsed, these tribes moved eastwards in the country through a series of migrations and settled in areas that are currently located in the states of Delhi, Haryana, Uttarakhand, and Uttar Pradesh. The later Vedas and commentaries were therefore written in an environment of increasing migrations and urbanisation of an essentially agrarian economy. The group of Vedic texts, Shrutis and Smrutis, represent a long textual history of India and Hinduism that documented the developments of human evolution and progress in theory and praxis over the course of almost a millennium (Elby, 2014). Figure 2 shows a timeline of the Vedic texts and the bodies of knowledge contained inside these texts (Encyclopaedia

Table 2 The Vedic texts

Vedic texts			
I. Shruti: What is heard		II. Smruti: What is recollected	
Rigveda	Oldest Veda with 1028 hymns	Upavedas: Applied science or art	Ayur, Dhanur, Gandharva, Sthapatya
Yajurveda	Book of Sacrifices	Vedangas: Six disciplines required to study the Vedas	Shiksa, Chandas, Vyakrana, Nirukta, Jyotish, Kalpa
Samaveda	Book of Melodies	Darshana: Six schools of philosophy	Nyaya, Vaisheshikha, Sankhya, Yoga, Mimansa, Vedanta
Atharvaveda	Book of remedies, spells, charms, magic	Shastras: Treatises on Hinduism	Niti, Smrutis
Each Veda has four commentaries and discussions in		Agamas: Collection of Scriptures	Shakti, Shaiva, Vaishnava
Samhitas	Mantras, hymns, prayers	Itihas: Narrations of human history	Mahabharata, Ramayana
Brahmanas	Prose commentaries	Puranas: Ancient, traditional legends	18 Maha Puranas, 18 Upa Puranas
Aranyakas	Discussions/Interpretations		
Upanishads	Philosophical commentaries		

Fig. 2 Estimated timeline of Vedic texts-Shrutis and Smrutis

Britannica, 2017; New World Encyclopedia, 2017; Vedic Academy, 2017). A note of caution that there is still no absolute dating for any Vedic text (Witzel, 2003).

To be able to assess the nature of science in the Vedic period, the internal evidence from the Vedic texts must be stated and laid out for the reader to interpret. The Vedic texts are divided into two categories: Shrutis and Smrutis, and the Shrutis precede the Smrutis. The sociocultural and religious beliefs among Hindus are that the Shrutis have no authors and are divine revelations that have been transcribed by seers and rishis (Bilimoria, 1989). The Smrutis, on the other hand, are texts authored by rishis and based on their memory, understandings and realisations. Smrutis are derivative and supplementary texts and may have changed over time, unlike the Shrutis, which are unquestionable truths. The Smrutis represent centuries of reflection and commentaries on the Vedas and Vedic traditions. Evidence of application and teaching of science found in the Shrutis and the Smrutis are described chronologically in the sections below, which will help us trace the evolution of scientific domains.

Science in the Rigveda

'The Rigveda is the earliest, the most venerable, obscure, distant and difficult for moderns to understand—hence is often misinterpreted or worse: used as a peg on which to hang an idea or a theory' (Staal, 2009, p. 107). The Rigveda is a collection of 1028 hymns dedicated to praise the deities and discussions on the origin of the universe (Witzel, 2003). Although the Rigveda does not offer direct evidence about the social or cultural life in the Vedic period, it offers ideas, clues and hints about the society and the lifestyle of the Indus people prevalent at that time. The Rigveda mentions farming, cattle rearing, horse racing, pastures, use of domesticated animals such as sheep, goats, asses, dogs for hunting, tracking and guarding, while bulls and oxen were used as draught animals (Mookerji, 1969). Cultivation of crops was a highly honoured and progressive occupation as farmers used manures and irrigation to enrich the soil. The Rigveda describes two types of irrigation systems, using rain and river waters, in farming (Ray, 2003; Singh, 2005). Also described are wells and the use of buckets to draw water from them where the buckets were tied to leather strings, pulled round a stone pulley and emptied into irrigation channels (Ray, 2003; Singh, 2005). Tanning of leather for bowstrings, slings, reins, whips and bags is mentioned, as are details about weaving and creating fabrics for various uses (Mookerji, 1969). There are descriptions of carpenters who made carts and chariots, draught wagons and artistic carvings, while technological advances in smelting are indicated by descriptions of metal and alloy tools, and descriptions of ornaments of metal and gold attest to the existence of goldsmiths and jewellery makers (Jamison & Brereton, 2014). The text mentions 100 cities fortified with stone and iron walls called ‘purs’, indicating the existence of extensive stone and metal work.

The Rigveda mentions a thriving economy and trade, including systems for money lending, bartering, debts, interest and donations (Reddy, 2011; Shendge, 2003). Descriptions of maritime trade using boats and ships propelled by oars and going out to sea are also found in the passages and there is a reference to a ship with 100 oars, ‘when he was lost in the supportless, foundationless, ungraspable ocean, you put forth your strength, oh Ashwins. You bore Bhujyu home, mounted on a ship with a hundred oars’ (Rigveda I.116.5, as cited in Frawley, 2012).

Science in the Atharvaveda

Composed in Vedic Sanskrit, the Atharvaveda is a collection of 730 hymns divided into 20 books. Zysk (1992) states that it is one of the oldest surviving records of evolutionary practices in religious medicine as it includes remedies in the form of mantras for treating a range of diseases from healing fractures to winning back spurned lovers. The Atharvaveda is an important text and acts as the roots of Ayurveda and Yoga, which are highly relevant and popular today (Wujastyk, 2003).

‘Pain in the head, affliction in the eye and ailment of the body, all that shall the kushtha heal, a divine powerful remedy, forsooth!’ (Atharvaveda, 5.4 as cited in Bloomfield, 1897). This is a mantra and prayer to the kushtha plant to reduce fever and related problems. The kushtha, *saussurea costus*, is a species of thistle native to South Asia and is a remedy for coughs, asthma and fever. Another remedy against persistent coughs, as suggested by the Atharvaveda, is a spell that will induce the cough to fly away and leave the patient cured. The spell reads as follows:

> As the soul with the soul’s desires swiftly to a distance flies, thus do thou, O cough, fly forth along the soul’s course of flight. As a well-sharpened arrow swiftly to a distance flies, thus do thou, O cough, fly forth along the expanse of the earth. As the rays of the sun swiftly to a distance fly, thus do thou, O cough, fly forth along the flood of the sea. (Atharvaveda 6.105 as cited in Bloomfield, 1897)

The Atharvaveda is a religious discourse that also includes herbal remedies for fevers, leprosy, jaundice, dropsy, coughs, scrofula, baldness, impotence as well as charms to protect against demons, sorcerers and jealous enemies. Additionally, the Atharvaveda offers spells to win over lovers, gain passionate companions, avoid abandonment and jealousy and other emotional ailments (Mookerji, 1969). The Atharvaveda offers information to guide the practices of daily life and is a storehouse of information on mental and physical health. This holistic perspective of wellbeing, which takes into consideration the emotional, mental and physical aspects of humans, is a notion that has only recently come under the purview of health sciences in modern society but was known to the people of Vedic times.

Science in the Yajurveda and the Samaveda

'May my rice plants and my barley, and my beans and my sesame, and my kidney-beans and my vetches, and my pearl millet and my proso millet, and my sorghum and my wild rice, and my wheat and my lentils, prosper by sacrifice' (Shukla Yajurveda 18.12 as cited in Griffith, 1899, p. 163).

Through its mantras for sacrifices and offerings, the Yajurveda provides indirect information about agriculture, economics and social life during the Vedic period. Derived from the root word yaj, which means to sacrifice or worship, and ved, which means to know, the Yajurveda is the knowledge of sacrificial texts and rituals (Griffith, 1899). From materials and ingredients required for sacrifices and the shapes and dimensions of altars, scholars have made inferences about the application of the sciences and mathematics.

The Samaveda is the Veda of melodies and chants whose 1875 verses are primarily derived from the Rigveda and is also known as the musical version of the Rigveda (Raghavan, 1962). The tradition of classical Indian music and dance known as Sangita is rooted in the sonic and musical dimensions of Samaveda (Beck, 1995) and the recital of the sacred mantras and verses in a melody and accompanied by musical instruments is one of the ways of performing religion in India (Beck, 1995). Existence of musical instruments such as the veena and lute are noted in the text as are musical notations in descending order from one to seven and the number of melodies recorded exceeds 8000, where each melody has a name (Mookerji, 1969; Raghavan, 1962). The Samaveda thus is one of the earliest guides on the theory and practice of music and singing in Indian history and the integration of music and sounds is seen as the journey of the individual soul towards the divine (Rejimon, 2018).

Science in the Upavedas

The Upavedas and the Vedangas are part of the Smruti texts (see Table 2), which means that they were written by rishis, sages or learned scholars, after the four Vedas and as commentaries or supporting texts to the Vedas. The Upavedas are regarded as supplementary to the Vedas and are of four types: Ayurveda (medicine), Dhanurveda (archery and warfare), Sthapatyaveda (architecture) and Gandharvaveda (music and dance) (Mukherjee, 2001; Oxford Reference, 2017; Patton 1994). Of these, the first three texts are rich in the use and application of science, some of which are commonly found today in India and beyond. Let us look at the three Upavedas briefly to understand the application and use of science.

Ayurveda

Literally translated as the science of life, this Upaveda also includes the Kamashastra (gratification and fulfillment) and Krishishastra (agriculture and care of animals). Ayurveda emphasises holistic prevention and maintaining a balance in one's life at the mental, physical and spiritual levels. Its two great classic texts are the Charaka Samhita and the Sushruta Samhita (Bhishagratna, 1907; Kumar, Vijayakumar, Govindarajan, & Pushpangadan, 2007; Shastri, 2003). The Charaka Samhita presents the theoretical foundations of Ayurveda and details about kayachikitsa (internal medicine), the pancha bhuta (five elements of air, earth, water, space, and ether), and the three components of our body known as kapha, vata and pitta, which must be balanced to achieve stability and good health. The Sushruta Samhita is the earliest text on surgery and was written by Sushruta (Bhishagratna, 1907; Kumar, Vijayakumar, Govindarajan, & Pushpangadan, 2007; Shastri, 2003). Dick (1998) states that the field of Ayurvedic surgery arose from the necessity of dealing with the effects of war, which was raging in the country at that time. This text on the ethics, theory and practices of medicine and surgery is an important document and contains long discussions on blood as the fourth component of the human body. In the 184 chapters of the Sushruta Samhita, 1120 conditions are listed including injuries and illnesses related to ageing and mental illness, 120 surgical instruments are described, and 300 different surgical procedures are detailed, such as anesthesia, dissections of cadavers, rhinoplasty, cataract removal, and caesarian sections, to name a few (Kansupada & Sassani, 1997; Saraf & Parihar, 2007). There were separate branches of studies for horses and elephants and early veterinary science was in existence due to extensive horse and elephant cavalries.

Dhanurveda

Literally translated as knowledge about archery, the Dhanurveda is the Veda of military science and warfare. Besides instructions on ethical warfare, the Dhanurveda discusses Lohashastra (metallurgy or materials science), and offers instructions to make weapons strong, durable and sharp through various treatments such as heating, tempering, and cooling to make them indestructible (Kulkarni, 1952; Ray, 2003). Keeping weapons rust free was a concern of the Vedic warriors, for which the Dhanurveda provides a few solutions. Another category of weapons described in this text are what we know today as chemical or mechanical weapons. The Dhanurveda offers descriptions and instructions for creating fire arrows, poison arrows, arrows that change direction after launch, arrows that track a target by following sounds, and arrows that render the target unconscious or paralysed (Kulkarni, 1952; Ray, 2003).

Sthapatyaveda

This Upaveda addresses architecture, town planning and Vastushastra, or the science of dwellings. Vastushastra includes all kinds of buildings: residential, religious, military, and administrative. It also includes town planning, green spaces, markets, bridges and other constructions that are found in cities and towns. Third, Vastushastra also includes furniture, garments and ornaments, soil components, astronomical and astrological calculations that will affect the building and its users (Acharya, 1979). The objective of this Upaveda is to create balance and harmony between man, nature, and buildings to ensure peace, happiness and prosperity (Patra, 2006). Construction of buildings according to Vastushastra, is governed by the five main principles which are listed below, and is becoming increasingly popular in India (Acharya, 1981; Kramrisch, 1976; Rao, 1995).

1. Doctrine of orientation
2. Site planning
3. Proportions and measurements of buildings
4. Six canons of Vedic architecture
5. Aesthetics and character of the building.

Science in the Vedangas

The six Vedangas are known as the six limbs of Vedas and are disciplines that are associated with the study of the Vedas. These are as follows:

1. Shiksha for the study of phonetics and pronunciation
2. Vyakrana for the study of grammar and linguistics
3. Chanda for the study of prosody, metrics and intonation
4. Nirukta for the study of etymology and meanings of words
5. Jyotish for the study of auspicious times, astronomy, astrology
6. Kalpa for a detailed study of rituals.

Of these, Jyotish and Kalpa Vedangas are of particular interest due to their extensive use of science and mathematics.

Jyotish

The word Jyoti means light of the heavenly bodies and the Jyotish Vedanga investigates how these heavenly bodies affect human life. Whether one believes or not in Jyotish or astrology, the spherical astronomy and astronomical calculations in these texts have been proven to be empirical and rigorous by modern standards (Plamadjala, 2010). Jyotish does not teach astronomy but uses astronomy to understand the auspicious and appropriate times and days for sacrifices (Tiwari, 2014). The Brahmasiddhanta text of the Jyotish shows how to calculate time and organise calendars using the movement of planets, sun, moon and the earth. These calculations are based on the application of trigonometry and mathematics to theorise about planetary orbits, predict planetary positions, and calculate relative mean positions of celestial nodes and apsides (Plofker, 2009). The Jyotish texts present several mathematical formulae to calculate and predict the length of a day, time of sunrise and moon cycles (Ohashi, 1993; Plofker, 2009; Winternitz, 1963).

Kalpa

Kalpa, a Sanskrit word, means proper, good fit, competent (Monier-Williams, 1923). The texts of the Kalpa, the Kalpasutras, are short and clear directions for the proper execution of rituals and sacrifices. There are two texts within the Kalpasutras, the Srautasutras and the Smartasutras, and it is within the Srautasutras that reside the Sulbasutras. The Sulbasutras contain information about the proper construction of altars for various Vedic rituals and provide geometric formulae and constants (Plofker, 2009). The Sulbasutras bring together principles of mathematics and geometry to serve religion, as all the concepts explained in the texts are in relation to the construction of appropriate altars for sacrifices. Several researchers have published analyses and commentaries on the Sulbasutras and their contribution to knowledge. Most of the geometric procedures described in the Sulbasutras start with laying out a string, representing a straight line, in the east-west direction, which is then incorporated in the final geometric construction of the altar (Henderson, 2000; Price, 2000; Sengupta, 2010; Staal, 1999).

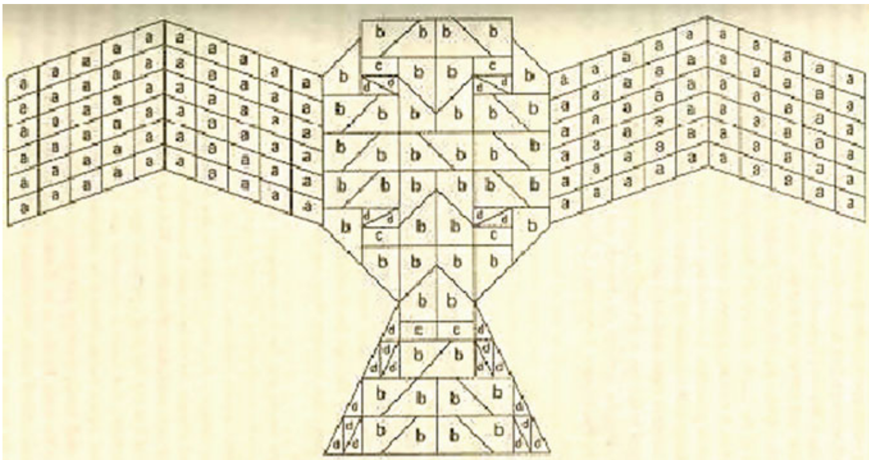

Fig. 3 First layer of the six-tipped bird-shaped altar (Staal, 1999)

Figure 3 shows the first layer of the five layers of fire-baked bricks that constitute the altar of Agnicayana, an altar shaped like a bird. Each layer uses 200 bricks of different shapes and dimensions and the bricks are to be laid according to their order and accompanied with specific mantras. Some of the constructions described in the Sulbasutras are as follows:

- Construction of a square with a side of given length
- Theorem on the square of the diagonal
- A square equal to the sum of two unequal squares
- A square equal to the difference of two squares
- Converting a rectangle into a square
- Converting a square into a circle and a circle into a square
- Arithmetic
- The square root of two, fractions, divide and average method, and equations (Henderson, 2000; Price, 2000; Sengupta, 2010; Staal, 1999).

If we consider that only a fraction of the Shrutis and the Smrutis have been recovered and analysed so far by scholars, the depth and breadth of science in these texts is extensive. The next question that arises then is: how was this knowledge imparted and passed on from one generation to another in the absence of books and written texts and what was the nature of schools and education at that time. Due to the lack of reliable information about the education system in the IVC, probably as the script is as yet undeciphered, the following sections will provide an overview of the schooling and education systems in the later period of Vedic India.

Schooling

Some scholars have divided the Vedic period into the early Vedic and the late Vedic periods. The Early Vedic Period is considered to be the time when the Vedas were written, and the Later Vedic Period is the period following it; this division too is contested but for the purposes of understanding the schooling system I will refer to the Early Vedic Period as the time from 1750 B.C. to 1000 B.C. and the Later Vedic Period from 1000 B.C. to 500 B.C. The reason for this division is an important difference between Early and Later Vedic education. Early Vedic schooling included all children, irrespective of gender or class and the schools imparted the same curriculum to boys and girls from all the four castes of Brahmins, Kshatriyas, Vaishyas and Shudras (Altekar, 2015; Banerji, 1989; Mookerji, 1969). The caste system became more rigid in the Later Vedic Period and the Vaishyas and Shudras began to be systematically excluded from learning the Vedas, thus disqualifying them from practicing religious professions and professions related to ruling and administration. The Vaishyas monopolised trading and mercantile professions while the Shudras became labourers and servants (Altekar, 2015). The rationale for excluding the Shudras was that they could not recite the Vedic hymns, as their mother tongue was not Sanskrit, and fear of mispronunciation of sacred hymns was the grounds for denying them access. Furthermore, in the Later Vedic Period, girls and women were excluded from schooling and were married at very young ages of eight or nine, which left no time for education (Altekar, 2015; Banerji, 1989; Mookerji, 1969).

Rituals Related to Schooling

There were three main rituals or ceremonies associated with schooling in a student's life. Education commenced at home in the early years of their lives, what we now term the preschool years. Parents were the first teachers following the ceremony of Vidyarambha, which marked the beginning of primary education between the ages of 4–7, and lessons were at home. The Upanayana ceremony was the second ritual associated with schooling when the child turned 8 years old and entered the stage of celibacy or brahmacharya, a stage governed by austerity and daily, annual and special rituals. Following the Upanayana, young boys usually left their parental homes and joined a gurukula or residential school. There was a special Upanayana for admission to medical and surgical courses taught by Sushruta, which was open to the three castes in the Later Vedic Period and excluded the Shudras. The final ceremony was Godana vrata, which marked the end of brahmacharya at 16 years of age, and was often followed by marriage, though there are examples of male students who continued to study after the age of 16 (Altekar, 2015; Banerji, 1989; Mookerji, 1969).

Types of Educational Institutions or Schools

There were two types of schools prevalent in this period and the most popular and common was the gurukulas or homes of teachers. The other type was what we now term a day school where students attended school for a few hours and then went home. The day schools were more popular with royal and rich families, while the majority of students left their parental homes and went to live in the homes of their teachers or gurus (Altekar, 2015; Patwardhan, Joglekar, Pathak & Vaidya, 2011). Each guru accepted, on an average, 15-20 students to live with him and become a part of his family and the students were assigned household chores and duties before and after their lessons (Altekar, 2015; Banerji, 1989; Mookerji, 1969). Along with learning to read and chant the scriptures, the gurukulas helped students become resourceful, independent and self-reliant; they learned what we now call essential life skills by living and studying with a group of peers. Every day the school started as early as 4:30 am and ended in the evening. Students had to beg alms at least once a week to learn humility and to seek support from society in supporting the education of future generations. The majority of the gurukulas were located within the limits of towns or villages and the students lived there for approximately 12 years, the time it took to study the Shrutis and Smrutis. The language of instruction and spoken language at the time was Sanskrit and learning was based on memorisation and oral language, as there were no books and the few writings existed on fragile and perishable materials. The guru usually taught each student individually, specifically for correction and feedback about pronunciation and the older students guided the younger ones for the same, as utmost priority was accorded to correct enunciation and intonation while chanting the scriptures (Altekar, 2015; Banerji, 1989; Mookerji, 1969). Some of the other types of educational institutions or associations were as follows:

1. Parishads: The parishads were an academy of experts and the source of expert commentaries on nuances of law and religion. Older students honed their knowledge through mutual discussions and debates and sought renowned specialists by travelling around the country to meet with parishads. The composition of the parishads was governed by some rules which included at least one expert in each Veda, experts in Shrutis and Smrutis, law and religion. The Upanishads, philosophical commentaries on the Vedas, are regarded as the outcomes of discussions and debates by learned gurus in various parishads. The knowledge generated by the parishads tended to offer guidelines for the betterment of the community and citizens (Altekar, 2015; Banerji, 1989; Mookerji, 1969).
2. Conferences: Conferences were organised by kings, where thinkers from around the country belonging to different schools and gurukulas were invited to meet and exchange their views (Banerji, 1989).
3. Courts of Kings: Courts were centres of learning where scholars flourished and were protected and supported by royal families. There were several centres of learning spread around the country that attracted renowned scholars (Mookerji, 1969).
4. Forest-based learning centres: Some of the Vedic texts were meant to be read in the forests and away from cities and villages. These were the Aranyakas, which are a part of the Shrutis. The Aranyakas were meant to be learned far away from villages and cities ‘from where one cannot see the roofs of settlement’ (Taittiriya, Aranyaka 2 as cited in Witzel, 2003). The contents of the Aranyakas include explanations not found in any other texts for complex rituals, theosophy, meditation and the secret meanings of sacrifices (Mookerji, 1969).

Curriculum and Pedagogy

The students learned the four Vedas and the six Vedangas and the core of learning was centred on religion, religious rituals and sacrifices. Students also learned how to fulfill one’s duties as children, students, spouses, citizens and parents. All teaching and learning occurred within the framework of Hinduism and students learned Vedic hymns related to rituals, geometry related to construction of sacrificial altars and elementary astronomy to understand the auspicious times for sacrifices and other rituals (Banerji, 1989).

Besides the Vedas, the students mastered the Upavedas, which included Dhanurveda, the art of warfare. The Brahmins mastered the bow, the Kshatriyas learned sword fighting, Vaishyas mastered the lance and the Shudras were taught to fight with a mace. The students learned Yoga to train their mind as a vehicle of supreme knowledge by relieving it of distraction (Banerji, 1989; Mookerji, 1969).

In the Later Vedic Period, liberal and professional education made an appearance in high schools and in the University of Takshashila (Banerji, 1989; Mookerji, 1969; Sharma & Sharma, 1996). More subjects were added to the curriculum and students could learn various subjects such as magic, making of perfumes, snake charming including venoms and antidotes, how to find hidden treasures, accounting and commerce, agriculture, cattle breeding, architecture, ship building, and weaving among others. Sculpting, architecture, coining, and painting thrived, stone and ivory became popular as mediums for sculpting, and artisans made their own tools such as brushes, chisels and colours. Smelting and welding processes were used to create finishes that did not rust (Altekar, 2015; Banerji, 1989; Mookerji, 1969; Sharma & Sharma, 1996).

The curriculum for Vaishyas was vast and detailed and involved many aspects of business and trade, such as understanding product quality, range, need, exploring new markets, learning new languages, custom duties, barter systems, banking and money lending. Different traders were organised into guilds with executive officers and funds (Altekar, 2015; Banerji, 1989; Mookerji, 1969; Sharma & Sharma, 1996). During this period, Brahmins ceased to learn professional skills and non-Brahmins ceased to master the Vedas, literature and philosophy. Brahmins started devoting more time and energy to the study of the Smrutis and the caste system became more rigid as did the inheritance of professions (Altekar, 2015; Mookerji, 1969).

Methods of Teaching

The teaching of the Vedic texts was divided into three distinct steps as follows:

1. Sravana or listening, which included six phases that started with initiation, recitation, understanding, comprehension, study of explanatory texts and eventually ascertained or demonstrated conclusion (Johnson, 2006; Rambachan, 1991).
2. Manana, which means contemplation, was a constant and ongoing process as the students reflected on what was heard and explained by the teacher (Johnson, 2006; Rambachan, 1991).
3. Nidhidhyasana is the contemplative and silent stage when the students have reached a state of knowing, which is the culmination of sravana and manana; listening is followed by reflection and experience and eventually the state of established knowing (Mookerji, 1969).

The Upanishads were taught mainly through dialogues, questions and answers, where the teacher provided broad topics and guidelines and students had to raise questions and discuss their doubts, thus laying the burden of learning mainly on the students and not the teacher (Mookerji, 1969). The intense focus on all aspects of oral learning led to the development of the Science of Logic, Vakovakyam, which includes argumentation and discussion (Bloomfield, 1897). The learning of all texts and Vedas was completely oral, based on rote learning and memorisation. Although there existed some tools for writing, learning was traditionally oral, a student learned on an average 12 shlokas or verses a day, which was 384 syllables (Max Mueller, as cited in Mookerji, 1969). The importance of the four Vedangas that focused on pronunciation, meaning, metre and rhythm served as vital tools to aid memorisation and mastery. Since the Vedic texts had been handed down with accuracy there was very little variation in the texts through time. Furthermore, the absence of written texts meant that there was no intermediary between the guru or the teacher, and shisya or the student, and the guru was the only source of knowledge (Altekar, 2015; Mookerji, 1969). The spread and dissemination of the sacred knowledge was thus controlled by the gurus and since there were no books, it could not be trafficked, appropriated, destroyed or manipulated. Being a guru thus became a religious duty and the guru was charged with passing on the heritage and wealth of the Vedas. A person, usually a Brahmin male, who had recited the highly revered Gayatri mantra 12,000 times was eligible to become a guru (Altekar, 2015; Staal, 1986) as long as he possessed the moral and spiritual qualifications and was well versed in the Vedas (Ghosh, 2001).

Assessment

Student learning was assessed through memorisation, exposition and interpretation of content. A scholar could be challenged by anyone at any time and should be able to prove himself worthy by winning the debate, this type of a contest was called Shastrartha and was carried out within the gurukulas as well as between different gurukulas (Handa, 1994).

Towards the Later Vedic Period, in approximately 600 B.C., there was an increase in agricultural production and population in India, leading to a rise in kingdoms in various parts of the country. This period is known as the time of 16 Mahajanapadas or 16 kingdoms and the creation of royal dynasties (Misra, 2001). Of these, the Maurya dynasty emerged as the most powerful and their rule extended almost to the entire Indian sub-continent and beyond. The rise of the Mauryan dynasty also saw the birth of Gautama Buddha and the beginnings of Buddhism and Jainism in India. The education and schooling, which until then was rooted in Hinduism, now began to be influenced by the new religions and later by Islam and Christianity and the following section will address these changes.

Buddhism and Islam in India

The rise of Buddhism in India, approximately from 500 B.C., brought about an important change where schooling and education was opened to all castes as long as the students vowed to follow the ascetic life and shunned worldly pleasures. Education was imparted through Viharas (Sharma & Sharma, 1996) where students resided as monks with their teachers. The Viharas were also centres of arts, crafts, weaving, architecture and painting that developed considerably under Buddhism (Ghosh, 2001). The main objective of Buddhist education was freedom from suffering and release from the cycle of rebirth and attainment of Nirvana, which is difficult to translate, and can be explained as a state of beatitude where one is free from happiness and sorrow. Although there is no specific mention of science education, details about medical studies appear in the texts of this period and the University of Takshashila offered a 7-year course in medicine and surgery (Jayapalan, 2005).

Access to the Viharas for women was limited and was governed by more stringent rules than for men but Buddhism did open more opportunities for women than earlier (Ghosh, 2001). Education flourished, and Nalanda University was one of the largest universities in the ancient world, with over 5000 students and 1500 teachers who resided for free on the campus (Huen Tsang as cited in Sharma & Sharma, 1996). This continued until the end of the twelfth century when Bakhtiyar Khilji invaded Nalanda, destroyed the university and set fire to its vast library.

Islamic rule in India from the twelfth to the nineteenth century changed the nature of education in the country. Some of the Muslim rulers promoted education while others actively destroyed Hindu and Buddhist centres of education. However, there was a resurgence of education and literacy under the Babur dynasty from 1526 A.D. Humayun and his son and successor Akbar invested a considerable amount of money and resources in building maktabs (primary schools) and madarasas (secondary schools), for Muslim children in the country (Jaffar, 1973). Children of all religions were allowed to attend, and they had a separate curriculum that allowed them to learn their own religious texts. The primary objective of Islamic education was religious, but Akbar wanted education to be able to allow students to earn a livelihood and the focus on skills and arts increased (Sharma & Sharma, 1996). Women and girls were excluded from going to school but were allowed to be tutored at home, which set back the progress made under Buddhism. Islamic rule continued until 1608 when the British East India Company's first ships docked in the port of Surat and launched the formal colonisation of India.

British Colonial Rule

The permanent impact of British rule on Indian education started with the Charter Act of 1813, when the British Parliament allotted 100,000 rupees to promote education among the Indian masses and allowed schools to be opened all over the country

(Keith, 1936). This paved the way for Christian missionaries to spread their religion as well as their language. Lord Macaulay's famous Minute on Education (Macaulay, 1835) stated that it was only through an English education that a class of persons, Indian in blood and colour, but English in tastes, opinions, morals and intellect could be created to serve the colonisers. With the advent of a European and British system of education, the teaching of science as a subject in school became common. While westernising Indians through their schools and colleges, the colonisers systematically delegitimised and denigrated Hinduism, Vedic education and any other form of indigenous education, including books and texts in vernacular languages, thus establishing the domination of Western science, which was used to acquire, possess and colonise lands and minds.

Concluding Thoughts

Science and mathematics were used by the Indus people primarily to sustain a growing population by providing food, shelter and safety, while in the Vedic period they were used to serve religion. The majority of references to science and mathematics in the Vedic period are related to the performance of religious sacrifices and as a way of displaying devotion and faith in Gods who were powerful and needed to be appeased or placated. As the Vedas symbolise Hinduism, the corroboration of Vedic science becomes a political and social concern, specifically in the wake of the British colonisation of India. The so-called superiority of European science, with its foundation of empiricism and empirical truth, versus indigenous science, found in religious texts in India, will always have a fractious relationship. Gottschalk (2012) states that the definitions of religion and science have crystallised only in the last few centuries as compared to the long history of their existence and humans have just begun to understand their meaning. Both, religion and science, will always have their supporters who invest heavily in one against the other; however, instead of being impeded by each other, science and religion should be viewed as intimately entwined and the concern should not be whether the science in the Vedas can or cannot be verified by modern scientific methods, but does the science in the Vedas help humanity in furthering its knowledge and improving our lives?

References

Acharya, P.K. (1979). *Hindu architecture in India and abroad* (Manasara series, Vol. 6). New Delhi: Oriental Books (original work published 1946 by Oxford University Press).

Acharya, P. K. (1981). *Indian architecture. According to Manasara silpashastra*. New Delhi: Oriental Books.

Allchin, B., & Allchin, R. (1982). *The rise of civilisation in India and Pakistan*. Cambridge: Cambridge University Press.

Altekar, A. S. (2015). *Education in Ancient India*. Delhi: Isha Books.

Banerji, S. C. (1989). *A companion to Sanskrit literature: Spanning a period of over three thousand years, containing brief accounts of authors, works, characters, technical terms, geographical names, myths, legends and several appendices*. New Delhi: Motilal Banarsidass Publishers.

BBC. (2017). *Indus valley: Home life*. Retrieved from http://www.bbc.co.uk/schools/primaryhistory/indus_valley/home_life/.

Beck, G. L. (1995). *Sonic theology: Hinduism and sacred sound*. New Delhi: Motilal Banarsidass Publishers.

Bhishagratna, K. L. (Ed.). (1907). *An English translation of the Sushruta Samhita based on original Sanskrit text* (Vol. 1). Calcutta: J. N.Bose.

Bilimoria, P. (1989). On the idea of authorless revelation (apaurusṣeya). In R. W. Perrett (Ed.), *Indian philosophy of religion* (pp. 143–166). Dordrecht: Springer.

Bloomfield, M. (Ed.). (1897). *Hymns of the Atharva-Veda: Together with extracts from the ritual books and the commentaries* (Vol. 1). Oxford: Clarendon Press.

Cucina, A., & Petrone, P. (2001). The 1997–2000 field seasons at Mehrgarh: Preliminary anthropological and taphonomic evidence. *South Asian Archaeology, 2005*(1), 79–84.

Danino, M. (2006). Humiliation in Hindu historical consciousness. *Social Alternatives, 25*(1), 44–49.

Dick, M. (1998). *The ancient Ayurvedic writings*. Retrieved from http://www.ayurveda.com/resources/articles/the-ancient-ayurvedic-writings.

Elby, T. (2014). A contemporary guide to the Vedas: A critical survey of the texts and literature. *Religion Compass, 8*(4), 128–138.

Encyclopaedia Britannica. (2017). *Indus Valley Civilisation*. Retrieved from https://www.britannica.com/.

Erdosy, G. (Ed.). (1995). *The Indo-Aryans of ancient South Asia: Language, material culture and ethnicity*. Berlin: Walter de Gruyter.

Frawley, D. (1994). *The myth of the Aryan invasion of India*. New Delhi: Voice of India.

Frawley, D. (2012). *Gods, sages and kings: Vedic secrets of ancient civilisation*. Twin Lakes, WI: Lotus Press.

Ghosh, S. C. (2001). *The history of education in ancient India, c. 3000 BC to AD 1192*. New Delhi: Munshiram Manoharlal Publishers.

Gottschalk, P. (2012). *Religion, science, and empire: Classifying Hinduism and Islam in British India*. New York, NY: Oxford University Press.

Griffith, R. (1899). *The texts of the white Yajurveda*. Benares, India: EJ Lazarus & Co.

Handa, O. (1994). *Buddhist art and antiquities of Himachal Pradesh, up to 8th century A.D.* New Delhi: Indus Publishing.

Havell, E. B. (1915). *The ancient and medieval architecture of India: A study of Indo-Aryan civilisation*. New Delhi: S. Chand.

Henderson, D. W. (2000). *Square roots in the Sulba Sutras: MAA Notes*. Cambridge: Cambridge University Press.

Jaffar, S. M. (1973). *Education in Muslim India*. New Delhi: Idarah-I Adabiyat-I Delli.

Jamison, S. W., & Brereton, J. P. (2014). *The Rigveda: The earliest religious poetry of India*. Oxford: Oxford University Press.

Jayapalan, N. (2005). *History of education in India*. New Delhi: Atlantic Publishers & Distributors.

Johnson, R. (2006). Locating non-Western enlightenment texts for a global curriculum. *Intercultural education, 17*(1), 21–32.

Kanopy Streaming Princeton University Library (Producer). (2016). *Indus Valley Civilisation [Video file]*. San Francisco, CA: The Great Courses.

Kansupada, K. B., & Sassani, J. W. (1997). Sushruta: The father of Indian surgery and ophthalmology. *Documenta Ophthalmologica, 93*(1), 159–167.

Keith, A. B. (1936). *A constitutional history of India, 1600–1935* (Vol. 5). London: Routledge.

Kenoyer, J. M. (1998). *Ancient cities of the Indus valley civilisation*. Karachi: Oxford University Press, American Institute of Pakistan Studies.

Kenoyer, J. M. (2006). Indus Valley Civilisation. In S. Wolpert (Ed.), *Encyclopedia of India*. Retrieved from http://aurarialibrary.idm.oclc.org/login?url=http://link.galegroup.com/apps/doc/CX3446500288/WHIC?u=auraria_main&xid=ffa10d77.

Kramrisch, S. (1976). *The Hindu temple*. New Delhi, India: Motilal Banarsidass Publishers.

Kulkarni, E. D. (1952). The Dhanurveda and its contribution to lexicography. *Bulletin of the Deccan College Research Institute, 14*(3), 208–220.

Kumar, B., Vijayakumar, M., Govindarajan, R., & Pushpangadan, P. (2007). Ethnopharmacological approaches to wound healing: Exploring medicinal plants of India. *Journal of Ethnopharmacology, 114*(2), 103–113.

Macaulay, T. B. (1835). Minute by the Hon'ble TB Macaulay, dated the 2nd February 1835. In *Selections from Educational Records, Part I (1781–1839).* Calcutta: Superintendent, Government Printing.

McComas, W. F., & Olson, J. K. (1998). The nature of science in international science education standards documents. In W. F. McComas (Ed.), *The nature of science in science education* (pp. 41–52). Dordrecht: Springer.

Misra, V. N. (2001). Prehistoric human colonization of India. *Journal of Biosciences, 26*(4), 491–531.

Monier-Williams, M. (1923). *A Sanskrit-English Dictionary*. Oxford: Oxford University Press.

Mookerji, R. K. (1969). *Ancient Indian education: Brahmanical and Buddhist*. Delhi: Motilal Banarsidass Publishers.

Mukherjee, P. K. (2001). Evaluation of Indian traditional medicine. *Drug Information Journal, 35*(2), 623–632.

New World Encyclopedia. (2018). *Indus Valley Civilisation*. Retrieved from http://www.newworldencyclopedia.org/entry/Indus_Valley_Civilisation.

Next Generation Science Standards. (2017). Retrieved from https://www.nextgenscience.org/.

Ohashi, Y. (1993). Development of astronomical observations in Vedic and post-Vedic India. *Indian Journal of History of Science, 28*(3), 185–251.

Oxford Reference. (2017). *Upaveda: Overview*. Retrieved from http://www.oxfordreference.com/view/10.1093/oi/authority.20110803114818711.

Patra, R. (2006). A Comparative study on Vaastu Shastra and Heidegger's 'building, dwelling and thinking'. *Asian Philosophy, 16*(3), 199–218.

Patton, L. L. (Ed.). (1994). *Authority, anxiety, and canon: Essays in Vedic interpretation*. New York, NY: SUNY Press.

Patwardhan, B., Joglekar, V., Pathak, N., & Vaidya, A. (2011). Vaidya-scientists: Catalysing Ayurveda renaissance. *Current Science, 100*(4), 476–483.

Petrie, C. A., Bates, J., Higham, T., & Singh, R. N. (2016). Feeding ancient cities in South Asia: Dating the adoption of rice, millet and tropical pulses in the Indus civilisation. *Antiquity, 90*(354), 1489–1504.

Plamadjala, N. (2010). *The role of devotion in Jyotish astrological system* (Unpublished Master's thesis). University of Iowa, Iowa. Retrieved from http://ir.uiowa.edu/etd/575.

Plofker, K. (2009). *Mathematics in India*. Princeton, NJ: Princeton University Press.

Possehl, G. L. (2002). *The Indus civilisation: A contemporary perspective*. Lanham, MD: Rowman Altamira.

Possehl, G. L. (2003). Indus Valley. In S. H. Katz (Ed.), *Encyclopedia of Food and Culture* (Vol. 2, pp. 267–273). Retrieved from http://aurarialibrary.idm.oclc.org/login?url=http://link.galegroup.com/apps/doc/CX3403400343/WHIC?u=auraria_main&xid=15ffcf59.

Prasanna, T. R. S. (2012). There is no scientific basis for the Aryan invasion theory. *Current Science, 103*(2), 216–221.

Price, J. F. (2000). *Applied geometry of the Sulba Sutras: MAA Notes*. Cambridge: Cambridge University Press.

Raghavan, V. (1962). Samaveda and Music. *Journal of the Music Academy of Madras, 33,* 127–133.

Rambachan, A. (1991). *Accomplishing the accomplished: The Vedas as a source of valid knowledge in Sankara* (Vol. 10). Hawaii: University of Hawaii Press.

Rao, R. (1991). *Dawn and devolution of the Indus civilisation*. New Delhi: Aditya Prakashan.
Rao, D. M. (1995). *Vaastushilpa shastra: The hidden treasures of Vaastushilpa shastra and Indian traditions*. Bangalore: S. B. S. Publishers.
Ray, P. (2003). *Vasista's dhanurveda samhita: Original Sanskrit text with translation into English*. New Delhi: J. P. Publishing House.
Reddy, K. (2011). *Indian History: For state civil services and other competitive examinations*. New Delhi: Tata McGraw Hill Education Private Limited.
Rejimon, P. K. (2018). Philosophical Foundations of Indian Music. *International Journal of Innovative Studies in Sociology and Humanities, 3*(1). Retrieved from http://ijissh.org/wp-content/uploads/2018/01/IJISSH-030102.pdf.
Roy, M. (2009). Agriculture in the Vedic period. *Indian Journal of History of Science, 44*(4), 497–520. Retrieved from http://insa.nic.in/writereaddata/UpLoadedFiles/IJHS/Vol44_4_2_MRoy.pdf.
Saraf, S., & Parihar, R. S. (2007). Sushruta: The first plastic surgeon in 600 BC. *The Internet Journal of Plastic Surgery*, *4*(2).
Science Council. (2017). *Our definition of science*. Retrieved from http://sciencecouncil.org/about-science/our-definition-of-science/.
Sengupta, P. K. (Ed.). (2010). *History of science and philosophy of science: A historical perspective of the evolution of ideas in science* (Vol. 13). New Delhi: Pearson Education India.
Shaffer, J. G., & Lichtenstein, D. A. (1995). The concepts of "cultural tradition" and "palaeoethnicity" in South Asian archaeology. In G. Erdosy (Ed.), *The Indo-Aryans of ancient south Asia* (pp. 126–154). New Delhi: Munshiram Manoharlal.
Sharma, R. N., & Sharma, R. K. (1996). *History of education in India*. New Delhi: Atlantic Publishers & Distributors.
Shastri, K. A. (2003). *Sushruta samhita of Sushruta*. Pune: Chaukhamba Sanskrit Pratishthan.
Shendge, M. (2003). *The civilized demons: The Harappans in Rigveda*. New Delhi: Abhinav Publications.
Shinde, V., & Willis, R. (2014). A new type of inscribed copper plate from Indus Valley (Harappan) civilisation. *Ancient Asia*, *5*. Retrieved from https://www.ancient-asia-journal.com/articles/10.5334/aa.12317/.
Singh, N. T. (2005). *Irrigation and soil salinity in the Indian subcontinent: past and present*. Bethlehem, PA: Lehigh University Press.
Singh, L. K. (2008). *Indian cultural heritage perspective for tourism*. New Delhi: Gyan Publishing House.
Singh, U. (2009). *A history of ancient and early medieval India: From the Stone Age to the 12th century*. New Delhi: Pearson Education India.
Siva, R. (2007). Status of natural dyes and dye-yielding plants in India. *Current Science, 92*(7), 916–925.
Staal, F. (1986). The sound of religion. *Numen*. 33(Fasc. 2), 33–64. https://doi.org/10.1163/156852786x00084.
Staal, F. (1999). Greek and Vedic geometry. *Journal of Indian Philosophy, 27*(1), 105–127.
Staal, F. (2009). *Discovering the Vedas: Origins, mantras, rituals, insights*. New Delhi: Penguin Books.
Thapar, B. K. (1975). Kalibangan: A Harappan metropolis beyond the Indus Valley. *Expedition, 17*(2), 19.
The University of Melbourne. (2017). *Agricultural Science*. Retrieved from http://bsc.unimelb.edu.au/majors/agricultural-science.
The Vedic Academy. (2017). Retrieved from http://www.thevedicacademy.com/history-study-material/.
Tiwari, S. (2014). *The Vedangas: Vedic heritage*. Delhi: Delhi University.
U.K. Department of Education. (2015). *Statutory guidance: National curriculum in England: science programmes of study*. Retrieved from https://www.gov.uk/government/publications/

national-curriculum-in-england-science-programmes-of-study/national-curriculum-in-england-science-programmes-of-study.
Vidale, M., & Frenez, D. (2015). Indus components in the iconography of a white marble cylinder seal from Konar Sandal south (Kerman, Iran). *South Asian Studies, 31*(1), 144–154.
Wheeler, M. (1968). *The Indus Civilisation*. Cambridge: CUP Archive.
Winternitz, M. (1963). *History of Indian literature*. New Delhi: Motilal Banarasidass Publishers.
Witzel, M. (2003). Vedas and Upanisads. In G. Flood (Ed.), *The Blackwell companion to Hinduism* (pp. 68–98). Oxford: Blackwell Publishing.
Wujastyk, D. (2003). *The roots of Ayurveda*. New Delhi: Penguin Books.
William Sharp. (n.d.). *Oxford Dictionary of National Biography*. Retrieved from https://en.wikipedia.org/wiki/William_Sharp_(homeopath).
Zysk, K. G. (1992). *Religious medicine: The history and evolution of Indian medicine*. Piscataway, NJ: Transaction Publishers.

Incubating Western Science Education in Tibetan Buddhist Monasteries in India

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Abstract India is known for its diversity of languages, cultures, ethnicities, religions and environment. However, the revisions to the current science curriculum and pedagogy in the National Curriculum Framework 2005 does not heed to the unique perspectives and value that this diversity brings to the vibrancy of its science classrooms and still imposes a monolithic curriculum in most schools. When I started my research into Tibetan Buddhist monastics' experiences of learning Western science, the literature was devoid of any lessons to draw from India or its neighbouring countries, despite the existence of various religions, cultures, languages and indigenous groups in the sub-continent where negotiation between traditional ways of knowing and Western science has been ongoing. Hence, in my research, I used the science education literature involving indigenous people and communities around the globe. These include indigenous people from the Americas, South Africa and Pacific Islands, where research has been undertaken about the experiences and challenges of learners in negotiating and integrating their traditional worldview with the worldview implicit in Western science education. In this chapter, I will share the experiences of monastics negotiating the intersection of Western science and Buddhist theology from an educational perspective and provide a brief history of programs that were set up to formalise Western science teaching in the Tibetan Buddhist monastic academic institutions of India.

Introduction

Initially, I will explain the historical events and goals that led to the introduction of Western science in the Tibetan Buddhist academic monasteries of India. Then, drawing from indigenous science education and cross-cultural research literature, I will reflect on specific challenges that need to be overcome in science education programs in order to serve the unique needs and goals of Tibetan monastics. From a sociocultural perspective, it is inevitable that the monastic would interpret scientific concepts

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based on prior knowledge and experience derived from their religion and culture. Using the theory of collateral learning, I will illustrate how monastics negotiate and resolve the differing schemas of the concept of life in Western science and Buddhism. Finally, I will share the key contributions made by various science projects that were involved in this educational effort since 1999. I will discuss some of the programmatic successes and challenges of these projects. I conclude with some recommendations for how India, given its diversity of religions, cultures and languages, could be the epicenter of research and training for cross-cultural and cross-religion science education that will, hopefully, empower all sections of its community, benefitting them materially and spiritually by integrating indigenous and modern science perspectives.

Background and Goals of Monastic Science Education

In the peaceful rural Tibetan refugee settlements of the southern Indian state of Karnataka, a rare educational experiment is taking place for the first time. Tibetan Buddhist monastics, steeped in their ancient Buddhist scholasticism, are trying their hands at Western science subjects including physics, life sciences and neurosciences. These refugee settlements were started in the 1960s and 1970s to maintain the distinct cultural and religious identity of Tibetan people in India after the Chinese annexation of Tibet in 1959. Therefore, all the four major Tibetan Buddhist sects (Gelug, Kagyu, Nyingma, and Sakya), including Tibet's native religion Bön, have established their sister monastery near these settlements, mostly situated in Karnataka, after the destruction of the original monastery in Tibet (Norbu, 2003). Introduction of Western science in the monastic community began after the Dalai Lama, at a large gathering of abbots of the major Geluk monasteries in south India in 1999, urged Tibetan Buddhist monasteries to take steps to begin science education (Project Background & Science Workshops, n.d.). This led to a growing interest and awareness of the importance of science education within the monastic community that led to a unanimous resolution, passed at the meeting of Tibetan religious heads in 2011, to initiate science education in their respective monasteries. Also in 2011, the Gelug monasteries decided to formally include science as part of their monastic academic curriculum and to participate in the Geshe Examination at the beginning of 2014 (Science studies to be introduced in Geluk Gyuktoe Chenmo, n.d.). The Gelug Geshe Examination is a rigorous examination taken over 6-years period after completion of monastic coursework and results in the highest degree in the Gelug order, known as Geshe Lharampa (Dreyfus, 2003). The Central Tibetan Administration estimates that there are about 40,000 monastics in India according to its 2010 census (see Appendix) and the Gelug order has the largest congregation. The fervor with which Tibetan Buddhists are embracing Western science has raised eyebrows regarding its intentions and goals since science and religion have a contested relation in the West. These questions include: What knowledge gap does Western science help to fill for a religious person? Why is science necessary for the spiritual attainment of Buddhist practitioners? What do monastics do with the newly learned scientific concepts and whether or not it drastically change their native worldview? These are pertinent and interesting questions that might come to everyone's mind and I hope to address some of these questions in the following pages.

Many of these questions are beyond the scope of this chapter. However, this chapter is an attempt to provide a glimpse into the ways in which Tibetan Buddhists embrace scientific knowledge from an educational perspective. It is important to note here that the goals of the science education movement in the Tibetan Buddhist community have been, to a large extent, influenced by its leader, His Holiness the Dalai Lama. In an introduction to a recent book, *Science and Philosophy in the Indian Buddhist Classics Vol. 1*, he writes, 'Today we live in an age when the power of science is so pervasive that no culture or society can escape its impact. In a way, there was no choice but for me to learn about science and embrace it with a sense of urgency' (Jinpa, Lama, & Coghlan, 2018, p. 3). He believes that science is an indomitable force in this age and that people of all cultures and societies should urgently engage with it rather than ignoring it. His two goals for engagement with science are primarily to expand the scope of our understanding of the world, and to ensure that science serves humanity. These same goals are also shared by the monastic community when they engage in science learning.

To briefly elaborate on the two goals of the Dalai Lama, he believes that contemporary science has focused primarily on the physical world at the expense of individual or personal experience, which has been the focus of inquiry in many contemplative traditions like his. Thus, by bringing the two traditions together, he thinks it would lead to a more holistic understanding of the external physical world and the inner experiential world (Tenzin Gyatso, 2005). By sharing the insights from contemplative practices about the workings of the mind with 'contemporary science' practitioners, he thinks this would allow science to work for the welfare of humanity both at the material and emotional level. Likewise, the Dalai Lama thinks that the contemplative tradition needs to reject or update the traditional accounts of the physical world with scientific accounts that have conclusive empirical evidence, such as evolution of life, cosmological events or constituents of matter (Jinpa, 2010). It is this last aspect of understanding how the monastics negotiate and make sense of scientific concepts in relation to their traditional Buddhist understanding of the world that is examined in this chapter. Unlike scientific explanations, the Buddhist taxonomical system and causal connections go beyond the physical empiricism of science, therefore it will be interesting to see how monastics relinquish or update their traditionally held ideas with the scientific ones. But before delving into this, it is important to understand how Tibetan Buddhists perceive science and how they deal with scientific knowledge.

Views of Science Among Tibetan Buddhists

Monastics, in general, share a positive attitude towards science from my experience of working with them and this can be attributed to the Dalai Lama who has advocated for engaging with science on various occasions. However, Jinpa (2003) presents three different conceptions of science among Tibetans, giving examples from notable Tibetan scholars such as the Dalai Lama, Gedun Chophel, Chukye Samten and non-English speaking Tibetan scholars. His first group considers science as a ‘rival philosophy’ whose claims about reality, especially their materialistic presentation of the mind, must be debated, challenged and questioned by Buddhists. Many non-English speaking Tibetan Buddhist scholars are believed to hold this view. The second group views science as ‘an ally’, providing empirical evidence for the claims that Buddhists have made and citing similarities between Buddhist and scientific methods, particularly the primacy of logical reasoning and empirical investigation. Jinpa gives Gedun Chophel and Chukye Samten as examples of those who held this view and who hoped to see some kind of Buddhist modernist movement. His last group views science and Buddhism as equal partners, the combination of the two providing a more comprehensive view of the human condition. In this category, he cites the Dalai Lama as an example due to his persistent effort to critically engage the two traditions in order to pursue the expansion of common human knowledge. However, views about science among ordinary monastics do not neatly fit into these categories.

In my study, monastics shared that before participating in science programs they held a dualist notion of science, where science is only related to the examination of external phenomena, while their tradition is more oriented towards examining internal or subjective phenomena (Sonam, 2017). However, as monastics engage in studying Western science subjects like psychology, neuroscience and life science, they gain a more nuanced understanding of science and accept that science does indeed investigate our mental experiences, although they believe that it is limited by its reductionist-materialistic methodological approach. Some monastics tend to equate science with technology, and their perception of science is that of a discipline involved in creating technology and mechanical objects. One of the monks shared the following experience of science before joining a science program: “At the time when I first enrolled in the science program, many monks have this fascination with science. For example, it is said that airplanes are made by science, electricity is made by science and I used to think how they made these. How are they able to make such things? I have this urge to know how these are made. This inspired me that there is something that sets apart science and I wanted to experience what makes it special.’ After taking science classes, he now thinks science is involved in unravelling the secrets of nature and he is optimistic that ‘science will eventually be able to explain the nature completely as science progresses. Science is always progressing. Science keeps undermining its own theory every ten or fifteen years.” Thus, this his view of science evolved through science learning and later developed a more authentic understanding of science.

Another interesting perspective shared is the belief that science has become an indomitable force in real life and also the lingua franca for communicating ideas among people and across cultures. Science has therefore, become something that Buddhist should know in order to remain relevant and share their Buddhist wisdom with the world at large. When asked about his motivation to learn science, this monk shared an anecdote about his friend: “he married into an affluent family and the mother-in-law told him that it is pity that he has grown up now, he has no education since he has been a monk from childhood”. Hence, he thinks learning science would make his friend more relevant both within and outside his monastic community. The varied expectations about science with which the monastics approach science learning necessitate an approach to the science curriculum that fulfills individual needs and goals of the monastics. The monastics’ experience of western science is significantly different from the experience of indigenous peoples around the world, due to its different history of colonisation and subjugation, however, there are lessons to draw. I now turn to the experience of science education among indigenous people and how it is relevant to the monastic science educational context.

Cross-Cultural Science Education

Researchers in the cross-cultural science education field have found that science and science education practices in schools primarily reflect the cultural values of white, middle-class Euro-Americans. Therefore, students who do not share such a background, often feel alienated when they find that their experiences outside of school are incompatible with the science that they are learning in school, resulting in them dropping out of science-related fields (Aikenhead & Michell, 2011; Aikenhead & Ogawa, 2007; Cajete, 1999; Chinn, 2007; Jegede & Aikenhead, 1999; Ogunniyi, 1988). Among Native Americans, it has been found that, although students perform well in early grades, their performance drops significantly at higher grades (Bang & Medin, 2010). This may have been caused by the lack of accommodation between their cultural values and practices and their early experiences of school science, resulting in loss of interest and withdrawal from science-related disciplines. Medin & Bang (2014) attributes this is due to the different epistemological orientation of the student’s culture which is not considered in school science classrooms. Similarly, in the South African context, it has been found that school science curriculum and practices rarely resonate with the rural life experiences of students, since the immediate environment and local culture in which learning occurs is neglected (Jegede, 1995; Ogunniyi, 1988; Ogunniyi, Jegede, Ogawa, Yandila, & Oladele, 1995). In addition to local culture, students are often strongly influenced by religious beliefs, thus necessitating the negotiation of a triad of knowledge systems—scientific, cultural and religious—at the same time when learning (Akpan & Anamuah-Mensah, 1992). Thus, teaching Western science in the confines of the monastery to Tibetan Buddhist monastics, who were acculturated by their religious education and training from an early age, is similar to introducing them to a new culture and way of thinking.

This necessitates rethinking the curricular and pedagogical practices that would best serve them.

Just as youth from non-western communities are involuntarily acculturated into learning Western science in the hope of better social and economic opportunities, monastic science education was initially also an imposition from the top, despite the pragmatic and global goals that were cited earlier. Monastics did not democratically come up with the idea of adding science education to their traditional curriculum. However, today the majority of monastics do believe in the reforms initiated by their spiritual leader and are interested in learning Western science. As mentioned earlier, the Dalai Lama encourages this reform with some sense of urgency. To achieve an effective science program, a sociocultural perspective of teaching and learning seems most appropriate in this context as the scientific knowledge to be transferred is mediated here by different cultural values and goals. From this sociocultural perspective, all teaching and learning is a cultural transmission-acquisition, therefore, science learning is an acculturation process where monastics need to gradually adopt the cultural beliefs and practices of Western science or Eurocentric science (Aikenhead, 2014). Such Western science or Eurocentric science has developed as part of a subculture of Euro-American cultures. Hence, it is important to acknowledge the cultural context of monastic learning that will include the opportunity to question the assumptions and presuppositions undergirding the epistemology, ontology, and axiology of the subculture of Western science and their own tradition (Cobern, 1994). Additionally, in order to create a congruent instructional pedagogical model, attention must be paid in order to take advantage of the specialised discourse practices of the monastics and their evolving self-identities and understand how science is learned, adopted, valued, and applied in their community.

Akenhead's (2014) three distinctions in the levels or experiences of cultural transmission-acquisition based on his experience working with Native American and Canadian First Nations youth is very relevant to the experiences of the Tibetan monastics. Those who experience *enculturation* are described as students who perceive their worldview to agree with a worldview endemic in Western science and are willing to enhance their everyday lives through science. This has some similarity to those who view science as *an ally,* the second category that Jinpa describes of the three different conceptions of science among Tibetan Buddhist community. From my experience, monastics who fall into this category share the characteristic of knowing more than two languages including English. *Assimilation* on the other end is described as the experience of students whose worldview does not align with Western science and are not amenable to change in their self-identities and everyday thinking through their institutional experiences. This resonates with the Jinpa's first group, who view science as a *rival philosophy*. Monastics who are only literate in Tibetan seem to fall in this category. In between *enculturation* and *assimilation* is *acculturation,* where students engage in selected modification of their current beliefs about the world under the influence of another culture, in this case, Western science. *Acculturation* occurs either through modifications made on a voluntary, informed, and explicit basis, leading to *autonomous acculturation* or made in an involuntarily, uninformed, and implicit way, resulting in *coercive acculturation.*

In the case of the monastics, the goal of science education is to achieve advanced understanding of canonical science and be able to critique Western science and its modes of knowledge production such that it, in turn, enhances their Buddhist worldview. At the same time, science is enriched through the unique Buddhist investigative tradition. Often, the Dalai Lama likens Western science to non-Buddhist schools in early Buddhist history that led to the incremental refinement and rigor of Buddhist beliefs, and in the contemporary world, he sees Western science as that counterpart knowledge tradition. For some monastics, the science education process would be an enculturation experience and they might become future scientists within the monastic community. For a large section of monastics, depending on the kind of instruction they might experience, might result in *autonomous* or *coercive acculturation*. In the case of *autonomous acculturation*, monastics might knowingly reconstruct their worldviews to include new concepts that they have learned in their science classes, resulting in a whole new understanding or revised worldview. For example, in my study, some of the monastics are willing to adopt the biological evolutionary account of human evolution and are ready to shun their belief in the Buddhist account of human evolution described in *Abhidharma* (translated as *Treasury of Knowledge*) because of the overwhelming scientific evidence. However, there are monastics who readily accept the scientific account of human evolution but on closer interrogation, they realizes that it contradicts their traditional taxonomy of six categories of sentient beings, where humans and animals hold distinct categories. Collapsing these two categories makes them uncomfortable and doubt their initial belief in the scientific account. This illustrates a case of *coercive acculturation*, where the monastics might adopt scientific ideas without knowing the ramification to their own worldview. As Aikenhead warns, the line between *assimilation* and *coercive acculturation* is blurred due to the nature of instruction that will either indoctrinate them intentionally or unknowingly. Educators involved with learners coming from non-western cultures must ensure at all times that their instruction does not result in assimilation through coercive acculturation.

Now that there is no going back on instituting science education in the Tibetan Buddhist monasteries, it is important to find ways to teach science that enriches and complements the monastics' traditional understanding of the world. As in the case of many cross-cultural science education efforts, there are sufficient grounds to fear of becoming completely indoctrinated in Western modes of thinking (Medin & Bang, 2014). There are numerous efforts to integrate indigenous knowledge into the existing school curriculum so that the learners maintain their traditional identity while enabling full social and economic participation. Similarly, the science curriculum and pedagogy for monastics must consider and make explicit connections to traditional knowledge possessed by the monastics while enabling various avenues for monastics to appropriate and discursively use their newly acquired scientific knowledge. It has been a challenge for many indigenous science education researchers to integrate indigenous knowledge with science learning due to the inexperience of local teachers and the nature of indigenous knowledge. The following section will illustrate the process and kinds of cognitive negotiation that occurs when learners are intentionally asked to integrate their indigenous knowledge—in this case, the Buddhist concept of life, with the scientific schema of life.

Confluence and Conflict

Jegede (1995) posited the theory of collateral learning as a cognitive phenomenon of students who experience discrepancy between their traditional explanation and the description given in the science classroom. In order to resolve the cognitive dissonance, students engage in different types of collateral learning depending on the degree of interaction and resolution of the two conflicting schemas. He identifies four types of collateral learning along a spectrum, with overlap between the categories. At one end is *parallel collateral learning*, where there is no interaction between the two conflicting schema and the schemas remain compartmentalised with no interaction in the learners' long-term memory. At the other end, there is the most interaction between conflicting schemas and it leads to modification of one schema in light of the other resulting in convergence towards commonality. This results in production of a new conception or holding on to both schemas for some logical reasons. This is *secured collateral learning* and is the most desired learning process for students who aren't science oriented and their worldview diverges significantly from a scientific worldview. In between are *dependent collateral learning*, where conflicting schemas challenge each other to the extent that one schema is modified without radically restructuring the worldview or domain of knowledge. This is more prevalent among learners who are unaware of the conflicting domains of knowledge and hence move between the domains unknowingly, unlike in secured collateral learning, where the learner is conscious of his movement. Finally, *simultaneous collateral learning* lies between *dependent* and *parallel collateral learning*, is where learning in one domain of knowledge enables learning of a similar concept in another domain.

Drawing on examples from my study with six Tibetan Buddhist monastics, they were conflicted between the schema of life in Buddhism and Western science (Sonam, 2017). One common Buddhist classification of the world is in terms of sentient versus non-sentient being while the corresponding category in Western science is living versus non-living things. By juxtaposing the Buddhist schema of sentient beings on evolutionary processes, in an attempt to reach a common or a new understanding of life, monks engage in different collateral learning. The interaction of these conflicting schemas also lead to various conjectures about the application of 'sentient' to evolution, and when life on Earth eventually became 'sentient' (see Fig. 1a).

Some monks conjecture that the first common ancestors are sentient, others assume that they could be both sentient and non-sentient. Their reason for attributing a sentient nature to the first single-celled organisms was as a result of their fascination when they got the opportunity to observe single-celled organisms showing characteristics similar to sentient being, such as reacting to its environment, locating food sources, and evading threats, in the science laboratory. However, this belief that single-celled organisms could be sentient challenges the monks to explain how

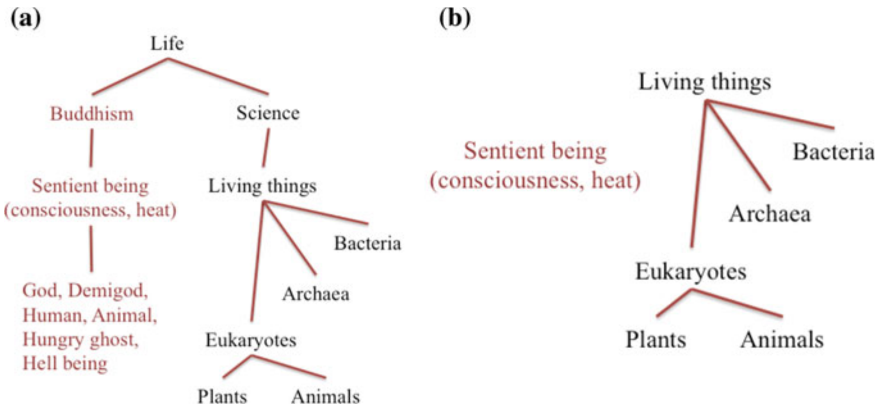

Fig. 1 **a** Buddhist versus science schema of life. **b** Sentient being versus the evolutionary tree

these single-celled organisms might later give rise to other organisms such as plants, which are definitively considered as non-sentient in Buddhism. The scientific view that life can possibly emerge from inanimate matter also contravenes the Buddhists' commitment to the belief that only a sentient being can give rise to another sentient being. These explanation gaps about the origin of plants and whether the first common ancestors were all sentient or not further causes more discussion among the monks.

Jampa, one of the monks in the study, claimed that plants and animals could not possibly come from a common ancestor and they should have their own lineage. He said,

> If I combine both science and Buddhism I would say plants came from plants, but first plants are simple and diversity in them occurred due to evolution. Similarly, animals' physical body also first came from simple bodies and due to Earth's environment there was more diversity later. This is acceptable to me.

Jampa's statement that 'If I combine both science and Buddhism' is suggestive of the compartmentalisation of science and Buddhist schemas of life in his head. This is a characteristic of parallel collateral learning, where the learner stores conflicting schemata in their long-term memory without much interaction between the two. He then goes on to say that if he were given an opportunity, he would consider that plants were initially simpler, and then evolution gave rise to the diversity in plants. Similarly, animals were first simple organisms that later gave rise to different animals through evolution. In essence, he is suggesting that plants and animals should have separate lineages, which runs counter to the central principle of common descent in evolution. In order to avoid conflating sentient and non-sentient, and also the evolutionary principle of common descent, he modifies the principle of common descent by suggesting that there should be a parallel phylogenetic tree for plants and animals. Here, since his modification of the evolutionary schema depended on the challenge posed by his religious worldview, this resembles the case of dependent collateral learning. Jampa was either unaware of his modified schema's influence on evolutionary theory, or he is willfully defying the central tenet of evolutionary theory in order to keep his original worldview intact. Based on his comments, if Jampa realises later in the discussion that he is defying a central tenet of evolution, he might revert to compartmentalising the two schemas.

Another monk, Tsering shared Jampa's view that plants and animals should have distinct lineages. However, he adopted a different accommodative mechanism to resolve the conflict. He was confident that our ancestral single-celled creatures were all initially sentient, but said, 'In between, due to certain change in the chemical composition, it is possible that cell's potential to host consciousness might have declined', and therefore became non-sentient, giving rise to plants. Those that remained sentient would give rise to the animal world. His creative explanation allows him to render both the scientific and Buddhist schemas of life valid. It neither distorts the principle of common ancestry in evolution, nor does it obviate the Buddhist notion that only a sentient being should give rise to another sentient being. Therefore, in terms of collateral learning, the amalgamation of two conflicting schemas towards a commonality is potentially a case of secured collateral learning (see Fig. 2a). However, the validity of such a novel explanation by Tsering seems contentious and raises questions about whether secured collateral learning should be the preferred goal in such cases.

Gawa held similar views that animals and plants should have distinct lineages. However, he had a different explanation of evolution that required sentient beings to remain sentient being. He said, 'Those which do not host consciousness would give rise to plants and trees. It is not possible that an initial sentient being was later transformed into a non-sentient.' Here, he objects to the possibility of transforming sentient beings into non-sentient beings and therefore, posits there might be two categories of single-celled organisms in early evolutionary history, those that can host consciousness, and those that cannot. Those that do not have consciousness would then give rise to plants and those with consciousness would give rise to the animals (Fig. 3).

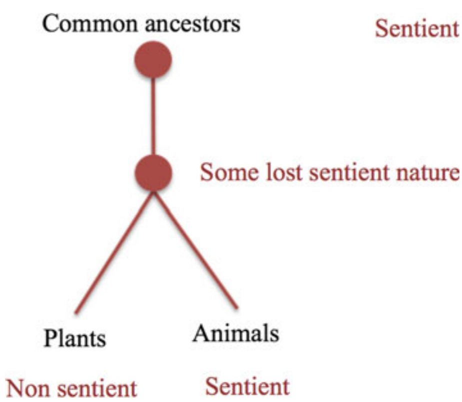

Fig. 2 Tsering's resolution of two schemas

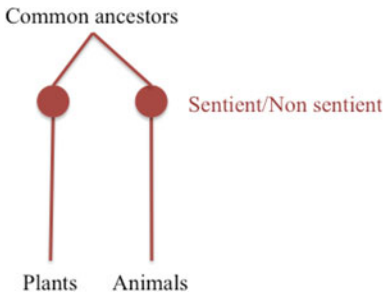

Fig. 3 Gawa's resolution of two schemas

Hence, the monks attempt to reconcile their traditional concept of life with the schema of life in science demonstrates that monastics experience conflict with their new learning and seek resolution. In an effort to find a resolution, in the case of Jampa, he was unaware that his claim for separate phylogenetic tree for plants and animals would go against the common descent principle in evolution. In the cases of Gawa and Tsering, their selective application of the concept of sentient beings in order to comply with the evolution of life in science is a questionable case of secured collateral learning which eventually changes to dependent or parallel collateral learning, since their claims lack conclusive evidence. The monks were unable to relinquish their traditional notions of life since their belief in the sentient nature of life is essential to Buddhism and this understanding of life is not limited to materialistic life observable on Earth. Life exists in three realms known as form, formless, and desire realms, and humans and animals are two of the six different life forms in the desire realm.

The above case illustrates the complexity of teaching science across cultures due to the variance in the nature of knowledge production and discursive practices between different cultures. This shows that teaching science across cultures is a challenging project and that normative science educational practices will not be sufficient to produce the desired results and goals of the community appropriating a Western science education.

Science Programs

To bring science education to the Tibetan monasteries, the Dalai Lama has sought help from various individual philanthropists and institutions, and provided the initial seed money to start programs. The programs include Science for Monks, Science meets Dharma and the Emory-Tibet Science Initiative, and they have each played a significant role in promoting science education in Tibetan monasteries and have achieved concrete results in the last two decades. The Dalai Lama has declared that this project is a hundred-year undertaking and its fruit will not be readily available for some time. Understandably, it has taken almost two decades since his public pronouncement at the gathering of monastic leaders in Gyumed monastery in 1999 to institute science education in monasteries. Today, science education has become a part of all the major

Gelug monasteries, and other Tibetan Buddhist sects are also following suit. Besides the inclusion of a science curriculum in monastic academic study, science centres with modern laboratory facilities and classrooms have been established at many of the monasteries. The science centres serve as spaces for science-related activities in the monastery including daily science classes, recruiting and training current and new science teachers and translators, organising science exhibitions and seminars. They thus act as the contact point for science educational and research innovation within and outside of the monasteries. Despite these successes, there are numerous challenges including teaching science in Tibetan, the development of a culturally appropriate curriculum and the availability of local science instructors that affect the sustainable development of science education in monasteries.

Translation

The Library of Tibetan Works & Archives (The Library) in Dharamshala worked with all three of the science programs as a local support institution before the science centres were started. Common to all the science programs, classes are taught by Western faculty members through an interpreter, usually a lay Tibetan with an undergraduate science degree. Western faculty members are still involved in science teaching due to the lack of science expertise among Tibetans. Although the younger monks and nuns are now more proficient in English language, it is not sufficient to read, understand and critique science textbooks and scientific articles on their own. All the instructional materials including textbooks, activity guides, PowerPoint presentations and assessments were translated into Tibetan, thus ensuring that science instruction is completely in Tibetan. This was intentional in order to revitalise the Tibetan language, since it suffered significant setbacks after the Chinese occupation of Tibet. It was also necessary since, initially, many of the monastics lacked English linguistic skills. As a result, a vast amount of science terminology, close to 6000 new words, were created in the last decade and some of these new terms have already entered into everyday monastics' discourse.

The small and dispersed demographics of Tibetan language users pose a challenge to the sustainability of science translation into Tibetan, due to the lack of incentives and opportunities to use the newly acquired Tibetan scientific discourse. Also, there are limitations in terms of financial and human resources that make it difficult to sustain the effort of developing new scientific vocabulary in Tibetan and creating space for its application. Initially, when the science programs began, there was a dearth of scientific literature available in Tibetan. However, today there are numerous science textbooks, translated science books, newspapers, and online resources available in Tibetan giving easy access to scientific information in the native language. Although these resources might have served well in achieving basic science literacy in the native language, the efficacy of learning science in Tibetan to reach the levels of discourse needed for dialogue and research collaboration with scientists, which is the ultimate goal of the science programs, remains questionable.

In terms of the mechanics of translation, one needs to be aware that translation itself is described as adding another layer of interpretation to the original source text (Small, 2008). Aikenhead (2005) cautions that 'the act of translating Western science into indigenous languages, and vice versa, is fraught with problems of incommensurability. Translations lose epistemological, ontological and axiological nuances, and hence cause misunderstandings' (p. 110). The confusion over the schema of life between Buddhism and science described earlier is partly due to the incommensurability of understanding of concept of life in these two knowledge domains. In science, no distinction is drawn between life and living things while in the Tibetan translation, the two words do not have the same meaning. The word life in Tibetan is easily understood as something that has consciousness or is a sentient being and needs frequent clarification for monastics in science classes to avoid confusion. Similarly, words such as organic and organism need to be translated with caution. This also illustrates the incommensurability of religious and scientific descriptions of the world. Kuhn in his popular philosophy of science book *The Structure of Scientific Revolutions* writes how even scientific constructs such as mass have different meanings as paradigms shifts, for example, from Newtonian gravity to Einstein's relativistic theory (Kuhn, 1970). He described these as having 'radical incommensurability'. However, later he recognises that there might be sufficient overlap in conceptual, linguistic and evidential procedures that might allow rational assessment. Similarly, to understand a construct such as life, science instruction must give ample opportunity for rational assessment of the meaning of key concepts between different knowledge traditions, so that learners are able to assess the limitations of each tradition.

Curriculum and Instruction

When the ETSI program first began its work to develop a science curriculum that caters to the needs of the monastic's community, there was no preexisting model to build the curriculum on. Since the monastics lacked basic science literacy, some were of the opinion that existing school science curricula should be used to build a foundation in science. Given that there is not much time available for teaching science in the monastery, using the existing school science curriculum would mean spending too much time teaching basic science and eventually students might lose interest in science. Hence, it was decided to develop a curriculum along the following themes in biology and neuroscience; (1) Structure and Function, (2) Evolution and Development, (3) Information Flow, Exchange and Storage, (4) Pathways and Transformation in Energy and Matter, (5) Systems—Interconnection, and Interaction; (6) Emergent Properties. The inherent challenge with this strategy was that monastics still require rudimentary knowledge about science to answer these questions. In the end, the curriculum is a blend of introduction of scientific facts and concepts, while making these relevant to monastics. Due to the monastics' interest in the science of meditation, human emotions and perception, a neuroscience course was developed specifically to deal with these topics. Despite the monks and nuns' abilities to grasp complex causal connections and engage in complex arguments, the majority of them lack simple arithmetic skills, thus making learning advanced science topics challenging. The fact that the monastics didn't have the opportunity to study mathematics from an early age makes it a challenging feat to impart mathematical thinking and skills to them as adults. I have seen expert monks who are unable to do simple mathematical operations despite repeated instruction. Since mathematics is critical to learning, talking and doing science, this is definitely an area that the current science curriculum should address. Another shortcoming of the current curriculum is that it does not explicitly make connections between scientific and Buddhist perspectives of the world. Although this is a challenging task, indigenous science education scholars have repeatedly argued for more representation and connection of indigenous knowledge in the science curriculum. I think as the monastics take charge of the existing curriculum, they will ensure that there is more occasion to draw from their own tradition in future science classes.

Key elements for the sustainable development of any science education program require qualified science instructors who understand the culture and discourse practices of their students. Currently, the shortage of school science teachers is a systemic issue in both developing as well as developed countries. Given the paucity of lay Tibetan science graduates who could serve the local Tibetan schools in India, it is even harder to find local science teachers who can cater to the monastics' needs. The lay Tibetan science teachers in the monastery often lack understanding of the epistemological and theological training that the monastics have been through, making it hard for them to connect with monastic thinking. I have myself experienced this first hand when I first taught science in the Sera monastery more than two decades ago. Often, I was unable to comprehend the monastics when they engaged in classroom discussions and debates using specialised monastic discursive practices. Hence, one solution for sustaining the science education project in monasteries is to develop monastic science instructors in the coming decades, and science programs have already been working on this front. In the last section, I will explain the historical beginnings of each science program, briefly highlighting the achievement of each program and their continuing efforts to bring science education to Tibetan monasteries in India.

Science for Monks

The Dalai Lama first gave the responsibility of introducing Western science in Buddhist monasteries to the Library of Tibetan Works & Archives in India, due to its non-sectarian status. The Library was begun as a Tibetan culture centre in exile and its archives and promotes all aspects of Tibetan culture, including the works of different Tibetan Buddhist sects. The Library's then director, Ven. Achok Rinpoche, started the Science for Monks (SfM) program in 1999. In 2000, a selected group of fifty monastic scholars from all the four sects of Tibetan Buddhism gathered at the Sera Monastery in South India to attend the first ever science workshop for monastics.

The workshop was taught, at the time, by two Western faculty members with the help of translators from the Library, financed by the office of the Dalai Lama. After that initial workshop, up until 2007, annual four-week workshops covering topics in physics, biology and neuroscience were held at various locations, mostly close to Tibetan settlements in India. These annual workshops were pilots for formal science teaching in the monasteries and were funded by the Sager Family Foundation.

In 2008, with continuing support from the Sager Family Foundation, Science for Monks began the Sager Science Leadership Institute with the goal of nurturing monastic science leaders in their respective monasteries and nunneries, who could share science with other monastics and laity in the neighbouring Tibetan refugee communities. The annual and often bi-annual 2–3 week long institute allowed the monastics to share their experiences teaching science while allowing them to deepen their science content and pedagogical knowledge. Through the institute, monastics also developed cross-cultural exhibits that showcased the Buddhist and scientific explanations of pertinent topics relevant to them and the larger society such as, the perception of the five senses and perspectives on climate change from two traditions. Museum professionals from the Exploratorium and the Smithsonian have supported the development of these exhibits and some of the exhibits have travelled nationally and internationally to the USA, Nepal and Bhutan.

The successful implementation and sustainability of the science programs in the monasteries depend on a multitude of factors including support from the monastery's leadership and administration. In order to garner the support of future leaders and administrators in the monastery, an introductory science workshop was started for monastic graduates in 2011, with the hope that these graduates might eventually take the reins of their monastery's administration and thus sustain science education in their monasteries. Science for Monks continues to hold the Science Leadership Institute and Graduate Science Introduction program and have recently started similar programs for nuns too. The program continues to expand its outreach, now engaging monastic communities around northern and north-eastern India, including Sikkim and Bhutan. More details and current activities about the program can be found on their website (www.scienceformonks.org).

Science Meets Dharma

When the Dalai Lama visited the Tibet Institute Rikon (TIR) in Switzerland in 1998, he sought their support in establishing science education in Tibetan Buddhist monasteries and in 2001, the Science meets Dharma (SmD) program was established ('The Science meets Dharma Project,' n.d.). The Science meets Dharma program was funded by the Swiss government and TIR. The program held regular science classes in the monasteries from 2003, first at Sera monastery in Bylakuppe and then at Drepung, Gaden and nunneries in Mundgod. All of these monasteries and nunneries are located in the south Indian state of Karnataka. Their daily science classes at the monastery were mostly taught by faculty from European countries with the help of lay Tibetan translators. The classes gave an easy introduction to the experience of science education for monks and nuns without having them to leave the confines of their monasteries. Many of the monks from this program later also participated in the programs run by Science for Monks and the Emory-Tibet Science Initiative program. The *SmD* program also held Study Week in the monastery every year where the monks and nuns select and explore a particular topic in science, and debate and dialogue about its connections to Buddhist philosophy and worldview (Tashi & Nyima, 2010). Unlike SfM, where the bulk of their faculty are from the USA, most of the faculty who came to teach for the SmD are European educators and taught for a duration of at least a year to two years in the monastery. Thus far, SmD has served over 400 monks and nuns since its inception in 2001 through two dozen European scholars, scientists and instructors.

Emory-Tibet Science Initiative

In 2006, the director of the Library, Geshe Lhakdor brought a letter from the Dalai Lama inviting Emory University to work with the Library to bring modern science education to the Tibetan monks and nuns in India. Emory graciously accepted the offer at the time and the following year, the Dalai Lama was appointed as the Presidential Distinguished Professor by Emory. This led to the establishment of the Emory-Tibet Science Initiative (ETSI) with the goal of developing a comprehensive and sustainable science curriculum for the Tibetan Buddhist monastics. Between 2007 and 2013, ETSI began its development and piloting of a science curriculum that was tailored to the needs of the monastics. In the summer of 2014, ETSI began the formal implementation of its six-year science curriculum with participants from nine monastic institutions including the six major Gelug monastic colleges. Since then, each summer ETSI brought groups of western science faculty to teach science at three different monastics sites from the USA. Starting with one cohort, each year a new cohort was added, and by 2019 there will be six cohorts altogether. Each cohort at each site has close to one hundred monks. As the number of cohorts increased with each year, additional faculty members were brought in and ETSI began recruiting instructors from academic and research institutions outside of Emory University. In the summer of 2018, a total of 97 faculty travelled to India mostly from the USA to teach the four topics: philosophy of science, physics, life science, and neuroscience, to a total of about 1200 monastics. As the implementation phase ends in 2019, ETSI is preparing to initiate a teacher development and a research skill development program, as part of its sustainability phase. The goal of the ETSI's sustainability phase is to develop indigenous monastic science educators who can teach its science curriculum and researchers who can participate in community-based research projects.

ETSI has also published over 13 science primers and plans to produce a total of 19 science primers by 2019, which were used as textbooks for each year before the end of its implementation phase. These primers are bilingual science textbooks. To facilitate the process of translation and standardisation of the scientific terms, an International

Conference on Science Translation into Tibetan has been held at Emory every year since 2009. The conference serves as a platform for Tibetan scholars with expertise in science translation to share their experience in methods of science translation and to deliberate on the standardisation of scientific lexicons in Tibetan, which will be used in the ETSI publications. Since the ETSI's inception, over 5000 scientific terms have been developed and standardised in Tibetan, which will be compiled into a bilingual science glossary. The full ETSI resources are available online (www.emorytibetscienceinitiative.com).

In order to produce monastics who are expert in science, the Tenzin Gyatso Science Scholars program was established in 2011. This program brings in talented and committed monastics from different monasteries to Emory University to study science at undergraduate level. While at Emory they also receive individualised tutoring by ETSI faculty in mathematics and other topics in science. The goal of the program is to deepen the scholars' science content knowledge, gain laboratory experience, and develop their pedagogical and technological skills, so that upon returning to their monasteries, they can shoulder the responsibility of science teaching to other monastics and advance the science activities in their monasteries. Since 2011, four cohorts of six monastics each spent two years at Emory studying under this program.

Conclusion

The various efforts to bring a science education that serves the needs and interests of the Tibetan monastics through these different programs is an exemplar of an inclusive and equitable science education. The Tibetans do not have the opportunity to carry out such reform in their own country, however, the freedom in India has allowed them to modernise their traditional monastic education by including modern science education while allowing the preservation of their traditional knowledge systems inherited from India. This synergy between Tibetan Buddhism and Western science has increased the confidence of the monastics about the veracity of the theoretical and empirical underpinnings of their own tradition and its ability to evaluate and explicate the reality, including human experience. At the same time, it has informed science on how to engage in the world ethically to promote human flourishing and well-being. Like the Tibetans monastic community, there exist a great diversity of peoples, cultures, and religions in India, who have collected vast amounts of knowledge and wisdom that have been passed on for generations, and that needs to be acknowledged and accommodated to make science relevant to their lives. While it is a challenge to include various perspectives in a centralised science curriculum, this is also a huge opportunity for India to showcase to the world how an equitable and inclusive science education can be achieved. The current Indian science education model rely more on an *enculturation* process that mostly harmonises with the cultural and social values of urban populations. Given much of India's population consists of numerous indigenous, ethnic, and religious groups, living in the large swaths of rural hinterlands whose lived experiences are still bound by their traditional belief systems; unless some modification is made to its current model of science education, would result in *assimilation* causing disorientation due to the loss of individual and communal identities, and may not serve the liberating goals of science education to escape 'from the vicious cycle of poverty, ignorance and superstition' as described in the National Curriculum Framework (p. 46).

Appendix

Tibetan Buddhist monastic population in India/Nepal/Bhutan (2010) by sects

	Religious sects	Monks	Nuns	Total
1	Nyingma	7005	1640	8645
2	Kagyu	6504	879	7383
3	Sakya	2842	241	3083
4	Gelug	17,787	893	18,680
5	Bon	576	52	628
6	Jonang	207	0	207
7	Bodong	57	0	57
8	Non-sectarian	348	448	796
	Total	35,326	4153	39,479

Source Religion and Culture Department, CTA, Dharamshala, India

References

Aikenhead, G. (2014). Acculturation. In R. Gunstone (Ed.), *Encyclopedia of science education* (pp. 1–3). Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-007-6165-0_348-2.
Aikenhead, G., & Michell, H. (2011). *Bridging cultures: Indigenous and scientific ways of knowing nature*. Don Mills, ON: Pearson Education.
Aikenhead, G. S. (2005). *Science education for everyday life: Evidence-based practice*. New York, NY: Teachers College Press.
Aikenhead, G. S., & Ogawa, M. (2007). Indigenous knowledge and science revisited. *Cultural Studies of Science Education, 2*(3), 539–620.
Akpan, O. E., & Anamuah-Mensah, J. (1992). The tricontextual milieu to science concept learning of an African child: Need for teaching model. *Journal of Science and Mathematics Education, 1,* 3–24.
Bang, M., & Medin, D. (2010). Cultural processes in science education: Supporting the navigation of multiple epistemologies. *Science Education, 94*(6), 1008–1026.
Cajete, G. (1999). *Igniting the sparkle: An indigenous science education model*. Durango, CO: Kivaki Press.

Chinn, P. W. U. (2007). Decolonizing methodologies and indigenous knowledge: The role of culture, place and personal experience in professional development. *Journal of Research in Science Teaching, 44*(9), 1247–1268. https://doi.org/10.1002/tea.20192.

Cobern, W. W. (1994). Worldview theory and conceptual change in science education. *Scientific Literacy and Cultural Studies Project.* Retrieved from http://scholarworks.wmich.edu/science_slcsp/15/.

Dreyfus, G. B. J. (2003). *The sound of two hands clapping: The education of a Tibetan Buddhist monk*. Berkeley, A: University of California Press.

Gyatso, T. (2005). *The universe in a single atom*. New York, NY: Morgan Road Books.

Jegede, O. J. (1995). Collateral learning and the eco-cultural paradigm in science and mathematics education in Africa. *Studies in Science Education, 25*(1), 97–137. Retrieved from http://www.tandfonline.com/doi/abs/10.1080/03057269508560051.

Jegede, O. J., & Aikenhead, G. S. (1999). Transcending cultural borders: Implications for science teaching. *Research in Science & Technological Education, 17*(1), 45–66.

Jinpa, T. (2003). Science as an Ally or a Rival Philosophy? In A. Wallace (Ed.), *Buddhism and science: Breaking new ground* (pp. 71–86). Columbia University Press.

Jinpa, T. (2010). Buddhism and science: How far can the dialogue proceed? *Zygon® Journal of Religion and Science*, *45*(4), 871–882. https://doi.org/10.1111/j.1467-9744.2010.01138.x.

Jinpa, T., Lama, D., & Coghlan, I. (2018). *Science and philosophy in the Indian Buddhist classics: The physical world*. Somerville, MA: Wisdom Publications.

Kuhn, T. (1970). *The structure of scientific revolutions*. Chicago, IL: Chicago University Press.

Medin, D. L., & Bang, M. (2014). *Who's asking? Native science, western science, and science education*. Cambridge, MA: MIT Press.

National Curriculum Framework. (2005). Retrieved from http://www.ncert.nic.in.

Norbu, D. (2003). The settlements: participation and integration. In D. Bernstorff, & H. Von Welck (Eds.), *Exile as challenge: The Tibetan diaspora. Orient Blackswan* (pp. 186–212). New Delhi, India: Orient Longman Private Limited.

Ogunniyi, M. B., Jegede, O. J., Ogawa, M., Yandila, C. D., & Oladele, F. K. (1995). Nature of worldview presuppositions among science teachers in Botswana, Indonesia, Japan, Nigeria, and the Philippines. *Journal of Research in Science Teaching, 32*(8), 817–831. https://doi.org/10.1002/tea.3660320805.

Ogunniyi, M. B. (1988). Adapting western science to traditional African culture. *International Journal of Science Education, 10*(1), 1–9.

Project Background & Science Workshops. (n.d.). Retrieved from http://www.Scienceformonksandnuns.org/.

Science studies to be introduced in Geluk Gyuktoe Chenmo. (n.d.). Retrieved November 15, 2015, from http://www.phayul.com/news/article.aspx?id=32255&t=1.

Science meets Dharma. Tibet Institute Rikon. (n.d.). Retrieved February 25, 2019, from http://www.tibet-institut.ch/content/smd/en/.

Small, M. L. (2008). Lost in translation: How not to make qualitative research more scientific. In *Report from workshop on interdisciplinary standards for systematic qualitative research.* Washington, DC: National Science Foundation. Retrieved from http://socthesis.fas.harvard.edu/files/socseniorthesis/files/small_lost.pdf.

Sonam, T. (2017). *Buddhism at crossroads: A case study of six Tibetan Buddhist monks navigating the intersection of Buddhist theology and western science*. Tucson, AZ: The University of Arizona Press.

Tashi, & Nyima, G. (2010). *Address to his holiness the XIVth Dalai Lama.* Retrieved from http://www.tibet-instut.ch.

von Welck, H., & Bernstorff, D. (Eds.). (2004). *Exile as challenge: The Tibetan diaspora*. Hyderabad: Orient Longman.

School Science and Science Teacher Education

Textual Texture of School Science

Gurjeet Kaur

Abstract Textbooks provide a vital curricular input that guides and establishes the academic setting for the teaching–learning process in India. They constitute the primary means through which legitimately endorsed knowledge in a subject comes to be disseminated by the curriculum framing agencies and consequently accessed by learners. They occupy a significant place in the educational process, especially in the case of a country like India which faces a huge number challenge and acute resource constraints, and where textbooks are the chief sources of valid knowledge, not only for students but also for teachers. Representation of knowledge in textbooks is, therefore, a crucial factor in shaping a large number of students' conceptual understandings, views and stances, and therefore need to be closely scrutinised. Presentation of the content, form, style and language of the textbook are all indicative of the specific position held about the nature of the learner, the nature of the subject matter and pedagogy. This position, however, is not overtly articulated, rather it has to be inferred and analysed. Making these textual tendencies visible would help major stakeholders in education assess them in light of contemporary understanding of education. This chapter is an attempt to closely examine the National Council of Educational Research and Training (NCERT) prescribed textbooks from class III to class X, to decipher their content and to analyse: (i) what their view of the subject matter is, (ii) how they situate the learner and (iii) on what pedagogical considerations they are premised. Textual tendencies are then traced across classes, moving vertically up the academic ladder.

Introduction

The use of textbooks in schools is probably as old as the phenomenon of formal schooling itself. While there has been a wide acknowledgment of the need to diversify curricular material, it simultaneously holds true that textbooks continue to be primary propellers of the curriculum. Especially in a number-challenged and

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resource-constrained country like India, textbooks ‘represent to each generation of students an officially sanctioned, authorised version of human knowledge and culture’ (Luke, De Castell, & Luke, 1989, p. viii). They are the key mediators between the intended and the enacted curriculum, and in that sense legitimise the national education discourse. Textbooks, through their presentation and style, put forward the state-endorsed view of the discipline. Since they are the sole available source of ‘valid knowledge’ for a substantial majority of Indian children and given the observation that, in many instances, the textbook may be dogmatically followed by teachers, the views presented in these texts need to be articulated, examined, analysed and critically discussed. Textbook analysis has emerged as a fertile area of research with studies of various types concentrating on a range of aspects, such as content and teaching methods, language and readability, assessment and evaluation, societal issues, illustrations, epistemologically oriented issues, holistic approach and reviews (Dimopoulos, Koulaidis, & Sklaveniti, 2005).

There has been a growing concern about the depiction of ‘science as static, finalistic, a historic, beyond doubt, universally applied knowledge, discovered by intelligent, individual scientists with no self-interest, after powerful efforts, which are ultimately crowned with success’ (Dimopoulos & Karamanidou, 2013, p. 61). Such an image is unrealistic and misleading. The question of whether science textbooks should only be about facts and currently accepted theories or should also concern themselves with the issue of communicating how these were arrived at and how scientific knowledge is created in human contexts may be treated as settled. Various educationists who have grappled with the issue have concluded that both the aspects merit importance in a curricular resource as fundamental as the textbook.

This chapter does not attempt or claim to undertake a detailed, dimensional review of textbooks on a pre-determined grid or a framework. Rather, it tries to take a more panoramic view. It looks at school science holistically, as depicted in textbooks, from four major vantage points- its placement within the curriculum, its depiction as subject matter, its portrayal as a human enterprise and in terms of its learner responsiveness. It describes the textbooks being currently prescribed by the National Council of Educational research and Training (NCERT) at primary, upper primary and secondary levels and tries to gauge and make explicit from these, through substantiating evidence, the national stance towards science pedagogy. In India, NCERT is the apex body responsible for formulating and articulating a national vision for school education. It is associated with the processes of curriculum development and textbook writing. The textbooks developed by the Council serve as exemplars for states and are therefore instrumental in preparing the nation-wide academic setting of a given school subject.

Science in Indian School Curriculum

Influenced collectively by the colonial push for western knowledge, the Nehruvian vision of modernity and the emergent need for skilled workers in a newly technologised society, science has always been accorded a prime position in the school curriculum in post-independence India. Science was seen as a way forward in building a new India and the theme recurred in the speeches and writings of national leaders as evidenced in the following articulation by Jawaharlal Nehru:

> Science is the spirit of the age and the dominating factor of the modern world. Even more than the present, the future belongs to science and to those who make friends with science and seek its help for the advancement of society. (Gopal, 1976, p. 806)

The discipline of Science in the Indian school system has also always been saddled with a lot of responsibility. It is frequently thought of as being the key to development of the nation. It is supposed to inculcate rationality and 'scientific temper', raise informed citizens, develop problem-solving skills and consequently liberate the citizenry from the 'vicious circle of ignorance, poverty and superstition' (NCERT, Position Paper-National Focus Group on Teaching of Science, 2006) Consequently it forms an important part of the syllabus for all classes. It also enjoys the reputation of being an intellectually elitist discipline, not easily available to everybody. Children desirous of taking up science as their choice stream of study in class XI often have to demonstrate their suitability by scoring a certain minimum number of marks in their class X examination.

Broadly the formal Indian school system is vertically tiered into 4 stages- Primary (classes I–V), Upper Primary (classes VI–VIII), Secondary (classes IX and X) and Higher Secondary (classes XI and XII). Evidently, influenced by the cognitive developmental view, the textbooks written for a specific stage, irrespective of the particular class, are similar in terms of their treatment of the content and writing style. Science as an exploration of the natural world is included within the realm of 'Environmental Studies' (EVS) at the primary stage. EVS is a composite area of study premised on the understanding that young children interact with their environment holistically and, therefore, it is unnatural for them to compartmentalise knowledge into watertight boundaries called 'subjects'. It, therefore, includes, within its purview, the study of the natural as well as the social environment of children. Textbooks are prescribed from class III onwards. Science as a separate subject, with a separate textbook, appears as part of the school syllabus at upper primary and secondary level. At higher secondary level, it becomes further branched into Physics, Chemistry and Biology with separate textbooks for each of these areas. This further fragments the understanding of the world into specificities, a phenomenon recognised as specialisation at advanced levels of education.

The Content of Science

It is easier perhaps to describe rather than define science. As a body of knowledge, it includes within its purview the various facts, principles, laws, theories and explanatory frameworks which are helpful in making sense of the natural and physical world around us. As a way of doing, it involves the various experiments and activities that are carried out during exploration and formulation of descriptions of the ways in which nature functions. As a way of thinking, it encompasses the various ideas, conjectures, hypotheses, predictions, estimations, claims, and refutations that are made during the course of investigations. A more succinct comment on science can be drawn from the position paper of the National Focus Group on Teaching of Science (2006) formed by the NCERT. The paper observes that the discipline of science involves

> observation, looking for regularities and patterns, making hypotheses, devising qualitative or mathematical models deducing their consequences, verification or falsification of theories through observation and controlled experiments, and thus arriving at principles, theories and laws governing the world… The laws of science are never viewed as fixed eternal truths. Even the most established and universal laws of science are always regarded as provisional, subject to modification in the light of new observations, experiments and analyses (p. 1)

To be truly representative of the discipline a textbook needs to depict and communicate all of its features to students. It should familiarise the students with the various concepts which have helped humanity make better sense of the natural world and how it functions. It should facilitate learners' acquisition of the methods and processes through which scientific knowledge is generated and validated and also help them to appreciate how our present understandings are the result of a long conceptual struggle and evolution. Examining the identified textbooks informs us that all the three aforementioned aspects are duly represented at the three stages. Observing, hypothesising and question-raising are skills that find due mention and representation across all grades and stages. The textbooks at the primary level constantly encourage children to think, discuss, debate, write and share ideas. Learners are persuaded to observe and question the happenings around themselves. The textbooks at primary level present the content through questions and activities. At the secondary stage too investigative activities are suggested at suitable junctures. What does not seem to get emphasised at higher stages is the cognitive effort and rigour required to plan investigations.

Science as a Community Constructed Enterprise

The history of science informs us that building scientific understandings is a non-linear process (Kuhn, 1962). Ideas are proposed, at times on the basis of experimental evidence or on the basis of creative insights, tried out, reworked, challenged, countered—leading to conceptual tensions which may not always be resolved. However, scientific knowledge can sometimes be presented in the textbooks as 'given' and static rather than as evolving and dynamic. Presentation of science as a systematic, linear process which always leads to definite answers can be misleading. A textbook which is true to the nature of the discipline must introduce it to its readers as an essentially human enterprise so as to break the alienating 'exclusivity' that is often associated with the subject. This would also be helpful in placing the subject within the intellectual ambit of children, who are then more likely to pursue the subject at higher levels of study. There are three ways in which the human ownership of scientific knowledge could be factored into the textbooks: bringing out the quest for knowledge as a shared human need which necessitates exploration and creation of both technology as well as concepts, use of historical instances to trace and highlight conceptual struggle, and highlighting the role of consensus in arriving at scientific knowledge. Spelling out the contexts in which particular concepts emerged is as important as highlighting the societal need for sophisticated technology. Sometimes the technology itself can catalyse concept formulations. For instance, the term 'work' was first used in connection with the use of steam engines to lift buckets of water out of flooded iron ore mines and came to be equated with weights lifted through certain heights. Bringing in these little details can facilitate the cultivation of significant disciplinary insights among students. There have been many proponents who have made a strong case for inclusion of the historical development of science in textbooks in order to promote scientific literacy and understanding of the structure of 'scientific method'. Cognitive theorists identify two primary categories of knowledge - declarative and procedural (Anderson, 1980, pp. 177–179). Declarative knowledge in science consists of facts, laws and theories that state how we presently explain the world and its phenomena. Operational knowledge is an appreciation of how these explanations were arrived at and what persuades us to collectively favour one explanation over another. If we agree, in principle, that science textbooks should concern themselves with inculcating both these kinds of understandings among students, then the entire book ethos has to be informed by this outlook. We may read the textbooks to find out whether the tone of the text, as demonstrated in its sentence construction, is declarative or procedural. For example, Fig. 1 shows a piece of text from a class VII textbook which tries to explain the role of leaves in food preparation for the plant.

While the concept of food preparation by plants has been brought in through a question, the answer is provided directly without any helpful information that could help children appreciate how the answer could possibly have been arrived at. The tone, therefore, remains authoritative. We find that though there is a visible attempt in several places to introduce students to the processes of knowledge building in science, there are several other places to which this idea has not been extended. What also

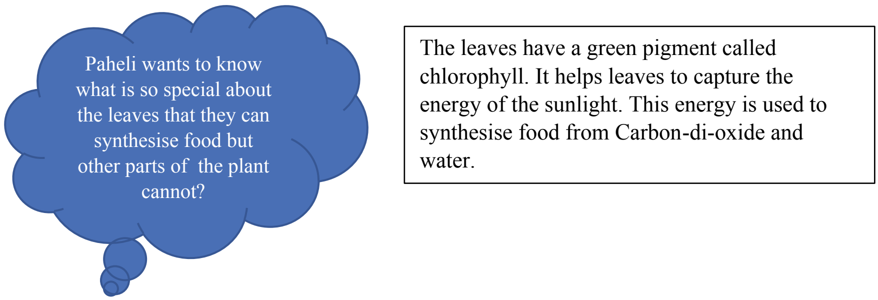

Fig. 1 Role of leaves in food preparation of plants

need to be communicated to students are the gaps in our present knowledge and the efforts that are currently underway to fill these gaps. Introducing students to these aspects would be more in tune with the dynamic nature of science.

This assertion can be illustrated by tracing the idea of water and mineral transport in plants as it is presented at a secondary level. In class IX, students are introduced to the structural details of the xylem tissue in the chapter titled 'Tissues' in these words:

> …complex tissues are made of more than one type of cells. All these cells coordinate to perform a common function. Xylem and phloem are examples of such complex tissues…Xylem consists of tracheid's, vessels, xylem parenchyma and xylem fibres… (p. 73)

In class X the topic appears as part of the chapter' Life Processes' under the subtopic 'Transportation in Plants'. The explanation of the phenomenon is initiated by first talking about the movement of water and minerals into the roots due to a difference in concentration of ions between the root and the soil which creates a water column by providing a steady push. Rationalising that this pressure by itself will be insufficient to account for water transport to the higher plant parts, the text then goes on to explain the process of transpiration

> However this pressure by itself is unlikely to be enough to move water over the heights that we commonly see in pants…Plants use another strategy to move water in the xylem upwards to the highest points. Provided that the plant has an adequate supply of water, the water which is lost through the stomata is replaced by water from the xylem vessels in the leaf. In fact, evaporation of water molecules from the cells of a leaf creates a suction which pulls water from the xylem cells of the roots. The loss of water in the form of vapour from the aerial parts of the plants is known as transpiration… (NCERT, Science-Textbook for class X)

Some significant aspects of the water transport phenomenon that are clarified through these explanations are: Root pressure as well as the suction in leaves are responsible for water transport. By reasoning that root pressure itself may not be sufficient to explain the phenomenon of water transport, the text is hinting at the thought processes which underlie the search for explanations of different phenomena. Then by defining transpiration as 'loss of water in the form of vapour from *aerial parts*', it is clarifying that transpiration could also occur from other photosynthesising structures of the plants.

The linguistic formulations are however declarative. The explanations do not attempt to portray the collective research efforts which allowed scientists to arrive at our present knowledge. This could have been brought in through a brief description of how the cohesion-tension theory originated at the end of nineteenth century. A mention of the fact that some aspects of the cohesion-tension theory still require experimental validation (Kim, Park, & Hwang, 2014) could have highlighted the dynamism of scientific knowledge. The topic also provides scope for building interdisciplinary connections through discussion of capillary action. Available research on children's ideas of the phenomenon of water transport shows that children hold an inadequate understanding of the concept (Barker, 1998). More specifically, most children are found to believe that most of the water that plants absorb is used up for preparation of food through photosynthesis (Çokadar & Özel, 2008). A reference to the fact that plants lose enormous amounts of water through transpiration does appear in class VI but is not revisited here (Science-Textbook for class VI, p. 139). Drawing children's attention to relevant details of transpiration could be helpful in addressing this idea. A well-rounded approach would be one that deals with a given topic in totality and looks at it from all angles.

There is a noteworthy attempt by the textbooks to highlight the role of the *collective* in defining concepts. This is evident in sentences of the following type taken from the class IX textbook:

> The word energy is very often used in our daily life, but in science **we** give it a definite meaning' (emphasis added) (p. 149) and 'To understand the way **we** view work and define work from the point of view of science… (emphasis added) (p. 147).

Locating the Learner

The sociological context of science has been brought into focus with the help of robust arguments put forward by many people who have engaged with the subject (Kuhn, 1962). It has been convincingly demonstrated that the practice of science involves people whose work is value-laden and socio-culturally contextualised. Consequently, a strong case has been made for science education in socio-cultural contexts (Kelly, Carlsen, & Cunningham, 1993). Even teachers are found to develop a more empowered attitude to science when scientific concepts are located in familiar and relevant contexts (Plonczak, 2008). It follows that there is a need to communicate science in familiar contexts to make the formal knowledge personally meaningful to children. Textbooks can begin by making an attempt to actively acknowledge that the learners, who constitute the readership of these textbooks, are situated in a multitude of specific life situations. Whether textbooks attempt to embed concepts in contexts may be gauged by looking at four aspects of content presentation: whether the content is mediated through characters, whether the understandings to be communicated have been woven into appropriate narratives (real life or otherwise), whether the characters in the narratives are placed in specific socio-cultural situations and whether the contexts chosen are pluralistic. What also merits attention is how the scientists and their work is represented within the textbooks. The following is an excerpt from the chapter 'Experiments with water' in the class V EVS textbook.

> Ayesha was waiting for dinner. Today Ammi was making her favourite food-puri and spicy potatoes. Ayesha watched as her mother rolled out the puri and put it in the hot oil. She saw that at first the puri sank to the bottom of the pan. As it puffed up, the puri came up and started floating on the oil. One puri did not puff up and did not float like the others. On seeing this, Ayesha took some

dough and rolled it into a ball. She flattened it and put it in a bowl of water. Alas! It sank to the bottom and stayed there.
Think what would happen if

- Ayesha put a puffed puri in a bowl of water. Would it sink or float?
- Would the cap of a plastic bottle sink or float in water?
- What would happen to a spoon?

The concept of floating and sinking could well have been communicated by asking students to recall observations from their daily lives and then making them carry out activities to find out which objects sink or float in water. However, embedding understanding in a familiar context could help to forge an organic connection between science and students' everyday lives. It is evident from the above excerpt that in this chapter children, through the example of Ayesha, are taken through various processes of science such as observing, hypothesising, reflecting, investigating, predicting and so on to encourage them to reflect upon the various factors that could determine the sinking or floating of objects in water. Researchers across countries have reported that there is a wide prevalence of certain stereotypical ideas about science and scientists. That is, people usually have a set view about what science is, how science is done, who does science and where science is done (Chambers, 1983; Mead & Metrax, 1957). The presentation of Ayesha as the investigator, in the example above, could be helpful in confronting various stereotypical ideas, such as scientists are usually middle-aged males, science can only be done in special environments like the laboratory and science requires sophisticated apparatus.

Science textbooks at the upper primary stage continue to be activity-based. The material required for performing these activities is likely to be chosen from items that are easily available and accessible to children. The illustrations that appear alongside the text depict both boys and girls. The questions whose answers can be answered through the text are frequently mediated through sketches of two children, a boy called Boojho (translates as Solve) and a girl called Paheli (translates as riddle) who appear from time to time and raise questions. The text suggests activities or provides explanations and clarifications which would lead to the answers to these questions. The text is addressed to the reader (a student of an upper primary class) but not to any specific reader. Paheli and Boojho ask many questions in upper primary textbooks, some of the interesting ones being: '*how could a single cell become such a big individual*'? (Science textbook for class VIII, p. 104) or when Paheli wondered how time was measured when pendulum clocks were not available (Science textbook for class VII, p. 148). There is a visible attempt to use children's natural curiosity as a springboard for introducing science concepts.

'Paheli' and 'Boojho' disappear at the Secondary stage. The writing style remains conversational at this level, and the textbook proceeds by citing examples from daily life, raising questions and providing explanations. First person 'we' is used whenever an activity is suggested or a clarification is given, implying that the authors are working together with the students in their exploration of the world.

Tracing the Tendencies

The discussion so far has tried to articulate the various vantage points for looking at scientific knowledge within the texts and has dwelt upon some broader considerations. It would be pertinent now to look for the emergent patterns about disciplines and related pedagogies as reflected in the textbooks. This section tries to map the picture of science as it emerges at the secondary level and the disciplinary image that is likely to be formed in the minds of class X students as they stand at the threshold of making an academic stream choice in class XI. Certain conclusions are drawn and corroborating evidence is also provided in many places.

Disciplinary Versus Integrated Approach

Traditionally there has existed a consensus among educators about the need for early school science to be integrated and division into separate specialisations to appear later but there have been different views about the nature and the appropriate time for these divisions to be introduced. The Kothari Education Commission (GOI, 1966) recommended the holistic study of the environment as EVS up to grade IV and branching into separate subjects from grade V onwards. The commission opined that the general science approach had not been successful because it made science appear 'formless and without structure' and ran contrary to its methodology (p. 198). The National Curriculum Framework (1988, p. 25) proposed that Environmental Studies be taught as a composite subject in classes I and II and split into EVS I and EVS II in classes III to V- one devoted to science and the other to social science. The National Curriculum Framework (2000) recommended Environmental Studies to be taught in primary classes and science and technology and social sciences to be introduced at upper primary level (p. 30). Presently, in accordance with the vision of the National Curriculum Framework (2005), Science is taught as EVS up to class V (p. 48) and as Science from class VI onward with a separate textbook. EVS is a composite area of study with scientific and social concepts woven around six core themes that run across the EVS syllabus of classes III to V. These are: family and friends (which includes four sub-themes: relationships, work and play, animals, plants), food, water, shelter, travel and things we make and do. To take a more holistic view, the science curriculum of classes VI–X is also founded on six broad areas: food, materials, the world of the living, moving things, people and ideas, how things work, natural phenomena and natural resources. 'The choice of themes and sub-themes reflects the thrust towards weakening disciplinary boundaries which is one of the central concerns of NCF-2005' (NCERT—Syllabus for Secondary and Higher Secondary Classes, p. 2). Despite this well-articulated intention the textbooks at upper primary and secondary level have found it difficult to move away from the 'in-science' subject boundaries of physics, chemistry and biology. Some of the titles of the chapters are themselves a giveaway, such as gravitation (class IX), tissues (class IX), light and shadows and reflections (class VI). Science in these classes, therefore, comes across as an agglomeration of concepts taken from different subjects but bound in a single cover. The idea of integrated science in its truest sense is not demonstrated.

Pedagogic Stance Is Stage-Specific

The shift in pedagogical approach is evident from one stage to another. At the primary stage, the attempt to access concepts through particular contexts is visible. At the upper primary stage, there is an attempt to introduce concepts through use of concrete materials and activities with the illustrated characters of two children mediating the text. At the secondary stage, the tone of the textbook becomes more formal and the illustrated characters disappear but activities remain. The approach of the textbooks changes from immediate to concrete to distanced on moving up the academic ladder. Across the grades and stages, there is a consistent and visible effort to link school science with the everyday life experiences and observations of children.

Hands-on Activities and Science Learning

Anchored presumably in the ‘discovery- learning’, ‘active -learning’, ‘child-centredness’ and ‘child as a constructor of knowledge’ rhetoric, there is a visible attempt, across classes and stages, to introduce the content through hands-on activities, as much as possible. The tendency may partially be attributed to the influence of the constructivist viewpoint, according to which knowledge is not something to be delivered to learners but something which is to be personally constructed by all individuals. The National Curriculum Framework (2005), which spells out the vision on which the textbooks are based, strongly advocates the desirability of acknowledging and duly providing for the primacy of the learner in the entire process of school education. It vehemently stresses the need to make available to children opportunities that would facilitate them in constructing knowledge in a personally meaningful manner.

Occasionally this ‘construction’ appears to be considered possible only through hands-on activities. The textbooks are replete with simple, doable activities requiring inexpensive, easily available materials. Across the grades, the emphasis seems to be on making conceptual understanding concrete and visualising, a tendency which needs to be used cautiously, since not everything can be directly observed. A negation of the process of abstraction could actually forge an incomplete understanding of the concepts and methods of science. The phenomenon of light is an example of such concepts. Though ‘visible’ in the traditional sense of the term, its comprehension requires a high degree of abstraction starting right from the notion of rays, which are only a theoretical construct but drawn diagrammatically, to illustrate the behaviour of light. Similarly, force and energy are two abstract ideas which are introduced quite early in school science.

Depiction of Science as a Self-initiated Investigation

While there are a lot of hands-on activities given in the textbooks, there is little scope for students to plan investigations on their own. The textbooks do not generally expect the students to initiate investigations, especially at upper primary and secondary level.

The tone of suggested activities is largely instructive and prescriptive with little scope for students to pose problems, think of experimental designs and work on them. In many cases, the conclusions are also drawn on behalf of students.

Most of the suggested activities at the upper primary stage begin by instructing the learner to set up and perform given tasks such as

> Take a rod or flat strip of a metal. Fix a few small wax pieces on the rod……Clamp the rod to a stand…Heat the other end of the rod and observe. (Science, Textbook for Class VII, p. 40)

The text further asks the students to share their observations and then goes on to summarise the observations and draw relevant inferences. However, there are no instances in which the students are required to independently design an investigation which would help them to find answers to authentic questions, that is, questions raised by them in real contexts. The questions/problems are provided by the textbook itself and the path to finding the answer is also provided. Learners are required to follow the steps systematically.

Portrayal of Scientists

The notion of science as an endeavour of specific people gets communicated in textbooks for classes IX and X. In primary classes, science concepts are communicated through particular contexts, as illustrated in the aforementioned example of Ayesha. In upper primary classes also, science is shown as being initiated and carried forward through questions raised as illustrated by two young children named Paheli and Boojho. The readers are drawn to the content through the questions and activities of these children. For example:

> Paheli has another (different from the one suggested in the book) arrangement of the cell and the bub. Will the torch bulb glow in the following arrangement? (refers to picture given alongside) (Science -textbook for class VI, p. 120).

In secondary classes, the specific work done by scientists and the notion of scientists as a group of people working closely together, begins to get emphasised. The following excerpts would perhaps help explain this observation:

> Modern day scientists have evolved two types of classification of matter based on their physical properties and chemical nature. (Science -textbook for class IX, p. 1)
>
> For a common person pure means having no adulteration. But, for a scientist all these things are actually mixtures of different substances and hence not pure. (Science -textbook for class IX, p. 14)

We might observe that the image of scientists as special people, engaged in a special kind of work begins to take shape in the references above. Class IX and X textbooks also include biographical notes on the lives of various scientists. These appear in boxes within the chapters. An analysis of these notes, carried out with the objective of revealing the image of science and scientists communicated through them, found that there are two significant ways in which these notes challenge the stereotypical image of scientists: (i) scientists learn from each other and carry forward each other's work, (ii) scientists may demonstrate cross-disciplinary interests. However 'the image of the scientist as a stern-looking Western, hardworking male still holds and the perception of science as a laborious discipline pursued by single-minded people, largely unaffected by social factors, remains uncontested (Kaur, 2015, p. 75). Also, the tone of the biographical notes remains focussed on scientists' achievements. It may be argued that, even though extensive information and specialisation is generally considered the hallmark of science, it is also important to make science accessible to the general public, especially in face of the evidence that people hold stereotypical images of occupations and also of the people in those occupations. Preferences that individuals develop towards certain occupations may be determined by the compatibility of these images with their own images of themselves (Gottfredson, 1996).

Use of Narratives

The issues of cultural recognition and representation of various social groups in the school curriculum have led to certain visible features being incorporated in the textbooks, such as the names of characters showing cultural diversity and the visuals showing both boys and girls as performing various activities. While the need to make science culturally relevant is being articulated in all fora, what needs to be simultaneously appreciated is that there is no single context in India but many varied contexts.

Inclusion of narratives in science textbooks can be helpful in embedding science in socio-cultural contexts. They help to put names and faces to people engaged in scientific endeavours. They also help in bringing the so-imagined 'exclusive' discipline of science within the everyday reach of people. Narratives, fictitious or real, can be useful ways to challenge prevalent stereotypes about science and scientists. Textbooks at upper primary and secondary levels do not use narratives as a pedagogic device and this characteristic merits deeper reflection. One could conjecture two possible reasons for this tendency.

The first could be the nomenclature of the study area itself. At the primary level, 'Environmental Studies' is a composite discipline that draws upon both science as well as social science, and hence the subject matter may be more amenable to inclusion of specific events and historical incidents. Social sciences may be thought of as being more responsive to the socio-cultural contexts of learners. In upper primary and 'secondary' classes, the subject is termed 'science', and hence objectivity and neutrality are perhaps prioritised. People shown as doing science are therefore nameless (or have names like Paheli and Boojho which have no cultural intonations) and are contextless. This point of view resonates with the universalistic view of science that suggests that scientific knowledge has to be founded on the cognitive criteria independent of the social, cultural and personal context of the learner. This view has been effectively countered by the evidence supporting the assertion that all scientific knowledge is developed and applied in specific contexts. The decontextualised approach to the science curriculum has been contested by the proponents of the 'humanistic approach' in science (Aikenhead, 2005).

The second possible reason that one can imagine, and which needs to be better understood, would be the argument that since the textbooks are prescribed nationally in India, a country of staggering diversity, bringing in particular contexts is possible only at the expense of leaving out several others. The counter view to this line of reasoning would be that diversity in contexts can be addressed and capitalised upon as a rich resource of science learning only by making it relevant to the curriculum and not by making it invisible. Neutrality of context deprives the science curriculum of opportunities to communicate a realistic image of science. Also, it needs to be simultaneously stressed that when diversity is overlooked then the perspectives of particular groups get represented in the name of 'universalism' and this is mostly the perspective of the middle or the dominant class. Consider the following excerpt from the chapter 'Garbage in, garbage out' of class IX textbook.

> You might have seen some children, sorting the garbage near your house or at other places. Observe the children at work and find out how they separate useful material from the garbage. They are actually helping us (p. 161).

The text is obviously addressed to children other than rag-pickers. Conversely, rag-picking children are not ordinarily expected to be present in the classroom and reading science textbooks. The text thus inadvertently leads to subtle 'othering' of children from certain sections of the society.

Place for Children's Ideas

Understanding about children and their learning informs us that children come to formal science instruction with a range of prior experiences. They have many preconceived notions about the functioning of the world around them. These ideas, variously referred to as intuitive notions, children's models, alternative conceptions or alternative frameworks in the research literature (Driver, Guesne, & Tiberghien, 1985, pp. 8–9) are formed on the basis of ordinary observations and experiences. They are repeatedly reinforced in everyday encounters and are therefore extremely robust and resistant to change. Many times these notions differ radically from the scientifically accepted explanations and could pose considerable conceptual difficulty for students. A few examples of such ideas are: continuous motion requires continuous force, things become heavier as they are lifted farther up from the ground and heat is a form of fluid and so on. Traditionally, considered as unnecessary inconveniences, these ideas were largely ignored by educators. However, contemporary wisdom looks at these ideas differently. It has come to be widely admitted that charting of students' future learning paths cannot be done without first studying and reflecting upon their pre-conceptions because their future course is decided by the nature of these pre-conceptions. There is a plethora of research literature now available on children's ideas pertaining to different concepts and phenomena. The textbooks need to begin to acknowledge this research evidence and build an appropriate response. An effort in this direction is more readily manifested at primary level where children's perspectives are brought in through their conversations or by challenging their perspectives through specific activities designed for the purpose. However, consistency in pedagogy is missing, that is, not all domains are addressed in this manner. At upper primary and secondary level there is an explicit attempt to address children's ideas in some places, as in the following excerpt:

> How do we know that something is living? Often, it is not easy to decide. We are told that plants are living things, but they do not appear to move like a dog or a pigeon. On the other hand, a car or bus can move, still we consider them as non-living. Plants and animals appear to grow in size with time. But then, at times, clouds in the sky also seem to grow in size. Does it mean that clouds are living? No! So, how does one distinguish between living and non-living things? (Science-Textbook for class VI, p. 87)

The passage above is clearly targeting students' ideas about living and non-living things and is referring to the available literature on the subject.

There is also a clear attempt to address the widely prevalent and well documented current consumption model of current electricity (Shipstone, 1985, p. 35) in the chapter titled 'Electricity' in the class X science textbook (p. 219). However such efforts are very few in number.

Treatment of History Within the Textbooks

The field of education in India has actively taken cognizance of the globally well-argued need for the subject matter of school science to be suitably responsive to the historical development of the discipline. History may be seen as entering the NCERT textbooks in five major ways:

(i) General statements: These make references to the past without highlighting the specifics. For example, 'Till 10,000 B.C., people were nomadic' (Science-Textbook for class VIII, p. 1)

(ii) Specific facts: These are factual statements. For example, 'Louis Pasteur discovered fermentation' (Science-Textbook for class VIII, p. 20)
(iii) A generic tracing of history: The history of a particular object or a phenomenon or an understanding is traced without dwelling upon the specifics. For example, the story of transport (Science-Textbook for class VI, pp. 95–96), and the discovery of silk (Science-Textbook for class VII, p. 30)
(iv) Detailed instances: Specific incidents or specifics of the process of a discovery/invention or an understanding reached are detailed out. For example, the discovery of the process of digestion by Dr Beaumont (Looking Around- EVS Textbook for class V, pp. 30–31; Science-Textbook for class VII, p. 16) and the speculation about the origin of life (Science-Textbook for class X, p. 150). In addition to these the textbooks for classes IX and X also contain biographical notes on many scientists
(v) Biographical notes: These appear as boxed items and give a description of a scientist's life and/or his key contributions.

Of the five ways described above, the last two may be considered to hold considerable educative potential for communicating the nature of science. At primary level science is taught as part of EVS and deals with concepts and issues of 'science' as well as 'social science'. Historicity in the context of science makes an appearance in class V textbooks and in this book there are four detailed historical descriptions of discoveries: Dr. Beaumont's discovery of the functioning of the stomach (pp. 30–31); George Mestral getting the idea of Velcro (p. 48); Ronald Ross' study of mosquitoes and malaria (pp. 74–75); and Mendel's experiments with peas (p. 198).

The search for other episodes of these type leads us to the following instances at upper primary and secondary level: the story of the discovery of magnets by a shepherd named Magnes (pp. 125–126, Class VI); the discovery of the functioning of the stomach by Dr. Beaumont (p. 16, Class VII); the discovery that the time period of a given pendulum is constant by Galileo (p. 147, Class VII); Alexander Fleming's work on a culture of disease-causing bacteria that led to the preparation of penicillin (p. 20, Class VIII); and the story of Dolly, the cloned sheep (p. 108, Class VIII).

In addition to the boxed biographical notes on many scientists, the following instances of historically informed episodes could be identified at the secondary level: arriving at the understanding of the structure of an atom (pp. 47–49, Class IX); the chronological development of our understanding of the structure of the cell (p. 58, Class IX); the periodic classification of elements (pp. 79–85, Class X); Mendel's experiments on garden peas (pp. 143–144, Class X); and speculations on the origin of life (p. 150, Class X).

Despite this appreciable effort there does not seem to be a consistent effort to use historical instances for strengthening conceptual understanding in science. Textbooks, especially the ones at upper primary and secondary level, seem to be 'peppered' with historical references without an effort to really place any given instance at the centre and conceptually learn from it. The idea that should be communicated, besides the importance of systematic investigation, is that doing science is also about responding to incidental happenings and using them as learning opportunities. Teachers, who are the key mediators of textbooks, also need to be cued about using them. Noticeably, while textbooks at primary level provide guidelines to teachers at certain junctures, those at upper primary and secondary level do not. In the case of the structure of atom, where there is a serious attempt to approach the subject historically, the various models are presented linearly, one after the other, by giving evidence in favour of the new model and highlighting the shortcomings of the older ones. This makes the process seem neatly unidirectional without making an attempt to demonstrate the inherent revisioning of ideas and presentation of counter views, which are intrinsic to the phenomenon of knowledge building in science. This is however attempted, to a certain extent, in the case of the development of the periodic classification of elements.

Concluding Comments

In many ways, school textbooks in India do try to respond to the prevailing discourses in education. Science is depicted, in equal measure, as a way of doing and as a way of thinking. Relevant and doable activities are suggested throughout to support conceptual comprehension. Across the stages, students are constantly cued to think of reasons for particular observations or predict results. There are fewer opportunities, however, for students to devise their own ways to go about finding answers to particular questions. The activities, therefore, tend to become prescriptive. Acknowledging the current emphasis of placing conceptual understandings in historical contexts, there is an all-pervasive effort to cite historical instances which show how a discovery was made or the method of investigation followed by particular scientists, even though the approach cannot be termed as historical because it masks the conceptual struggles and messiness involved in arriving at a shared scientific understanding of the world and its phenomena. There is also no visible effort to provide alternative perspectives, however weakly supported, about any given particular explanation. Another aspect that needs more attention is the imperative to highlight that science is as much about the felt need to define new concepts as it is about discovering new things. There are also sporadic instances of the texts making an attempt to address children's alternative ideas on a subject by directly targeting them, but the approach is piecemeal instead of being consistent. It may, therefore, be concluded that while the textbooks for all classes seem to be adequately informed by contemporary thought in the field of education, what is required, perhaps, is persistence, permeation and a consistency of approach.

References

Aikenhead, G. S. (2005). *Science education for everyday life: Evidence based practice*. New York, NY: Teachers College Press.

Anderson, J. R. (1980). *Cognitive psychology and its implications*. San Francisco, CA: Freeman.

Barker, M. (1998). Understanding transpiration—More than meets the eye. *Journal of Biological Education, 33,* 17–20.

Chambers, D. W. (1983). Stereotypic images of the scientist: The draw-a-scientist test. *Science Education, 67*(2), 255–265.

Çokadar, H., & Özel, M. (2008). Elementary school students' ideas about water transport in plants. *Journal of Baltic Science Education, 7*(3), 155–164.

Dimopoulos, K., & Karamanidou, C. (2013). Towards a more epistemologically valid image of school science: Revealing the textuality of school science textbooks. In M. Khine (Ed.), *Critical analysis of science textbooks* (pp. 61–77). Dordrecht: Springer.

Dimopoulos, K., Koulaidis, V., & Sklaveniti, S. (2005). Towards a framework of socio-linguistic analysis of science textbooks: The Greek case. *Research in Science Education, 35,* 173–195.

Driver, R., Guesne, E., & Tiberghien, A. (Eds.). (1985). *Children's ideas in science*. Milton Keynes: Open University Press.

Gopal, S. (Ed.). (1976). *Selected works of Jawaharlal Nehru* (Vol. 8). New Delhi: Orient Longman.

Gottfredson, L. S. (1996). Gottfredson's theory of circumscription and compromise. In D. Brown & L. Brooks (Eds.), *Career choice and development* (3rd ed., pp. 179–232). San Francisco, CA: Jossey-Bass.

Government of India. (1966). *Report of the Education Commission (1964–66): Education and national development*. New Delhi: Ministry of Education.

Kaur, G. (2015). Curricular images of scientists. *Economic and Political Weekly, 50*(36), 71–76.

Kelly, G. J., Carlsen, W. S., & Cunningham, C. M. (1993). Science education in socio-cultural context: Perspectives from sociology of science. *Science Education, 77*(2), 207–220.

Kim, H. K., Park, J., & Hwang, I. (2014). Investigating water transport through the xylem network in vascular plants. *Journal of Experimental Botany, 65*(7), 11895–11904.

Kuhn, T. S. (1962). *The structure of scientific revolutions* (1st ed.). Chicago, IL: Chicago University Press.

Looking around-Textbook for class V. (2008). New Delhi: NCERT.

Luke, C. J., De Castell, S., & Luke, A. (1989). Beyond criticism: The authority of the textbook. In S. De Castell, A. Luke, & C. Luke (Eds.), *Language, authority and criticism* (pp. 245–260). London: Falmer.

Mead, M., & Metrax, R. (1957). Image of the scientist among high school students: A pilot study. *Science, 126,* 384–390.

National Council of Educational Research and Training. (1988). *National curriculum for elementary and secondary education- A framework*. New Delhi: NCERT.

National Council of Educational Research and Training. (2000). *National curriculum framework for school education*. New Delhi: NCERT.

National Council of Educational Research and Training. (2005). *National curriculum framework.* Retrieved from http://www.ncert.nic.in/html/pdf/schoolcurriculum/framework05/prelims.pdf.

Plonczak, I. (2008). Science for all: Empowering elementary school teachers. *Education, Citizenship and Social Justice, 3*(2), 167–181.

Position paper-National focus group on teaching of science. (2006). New Delhi: NCERT.

Science-Textbook for class IX. (2006). New Delhi: NCERT.

Science-Textbook for class VI. (2006). New Delhi: NCERT.

Science-Textbook for class VII. (2007). New Delhi: NCERT.
Science-Textbook for class VIII. (2008). New Delhi: NCERT.
Science-Textbook for class X. (2006). New Delhi: NCERT.
Shipstone, D. (1985). Electricity in simple circuits. In R. Driver, E. Guesne & A. Tiberghien (Eds.), (1985). *Children's ideas in science* (pp. 33–51). Milton Keynes: Open University Press.
Syllabus for secondary and higher secondary classes. (2006). New Delhi: NCERT.

Examining Pre-service Science Teachers Pedagogical Orientations in an Era of Change in India

Garima Bansal, Umesh Ramnarain and David Schuster

Abstract This chapter examines the historical development of science education in India, beginning with the policy context in pre-independence India to the present day, with a specific focus on school science education and teacher education. Specifically, this study examines the pedagogical orientation of pre-service science teachers, who had been a part of two-year Bachelor of Education teacher education program in India. They had taught middle grades science during their school internship program in different genres of schools, ranging from state-funded to private-funded during internship. Assessment items in Pedagogy of Science Teaching Test (POSTT) were used to identify their pedagogical orientations, and reasons for their specific orientations were probed through interviews. It comes out that pre-service teachers develop varying pedagogical orientations, ranging from direct instruction to open inquiry, emerging from several school-related factors like class size, availability of resources, leadership guidance; discrepancies between professional development and school culture, and other personal constraints.

Introduction

Many countries are focusing on policy decisions with regards to curriculum design in science teaching and learning in order to prepare students for the demands of the twenty-first century. Because the success of any educational change depends upon how teachers perceive that change (Bryan & Abell, 1999), it seems crucial to understand how their beliefs and practices are constructed during professional

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development programs and influenced by various social and contextual factors in the schools.

For this study, we have adopted Friedrichsen, van Driel, and Abell's (2011) definition of a teacher's science teaching orientation as describing the beliefs that they hold regarding (a) a teacher's understanding of the goals and purposes of teaching science (b) their view of the practices of science as a discipline, and (c) their beliefs about science teaching and learning. Thus, while referring to the 'pedagogical orientations' of teachers towards science teaching we are referring to this collective set of beliefs.

This study focusses on the current Indian experience with curriculum restructuring of one of its teacher education program—Bachelor of Education (B.Ed.). In order to contextualise the study, we begin our chapter by tracing the historical roots of science education in the country. The discussion then moves on to delineating the current practices of school science education in the country. Elaborating the problems associated with school science education, and how teachers are held responsible for the poor execution of policy in classrooms, it moves on to examine pre-service teachers' pedagogical orientations towards science teaching, post-curricular reform in teacher education in the country, through a specific research study. The research study attempts to identify the pedagogical orientations of pre-service teachers graduating from a professional development program, namely the B.Ed., in India.

This study was conducted shortly after the introduction of a new curriculum that led to restructuring of the B.Ed. program, making it a two-year program instead of one year and offers an enhanced understanding of the effectiveness of the reform process. Further insights about socio-cultural and contextual factors that might affect the reform process may be gleaned from this study.

Background

Historical Roots of Science Education in India

This chapter traces the historical and ideological trajectory of science education (SE) in India to contextualise educational practices in science. Sangwan (1990) analyses complexities inherent in SE in pre-independence India. He identified three phases which SE underwent during the pre-independence era. In the first phase, the British colonizers displayed indifference towards the education of their Indian subjects due to an inherent belief that education would awaken their minds to escape the clutches of colonial rule. However, the second phase witnessed an extension of indigenous systems of education (Sanskritic education) in India. This move was criticised by influential Indian reformers who appealed for the diffusion of European sciences into Indian education. With the pressing demand for engineers to tap water reservoirs through dams, canals and the requirement of trained personnel for constructing roads and railways, an emphasis on SE was finally laid in the third phase. The ideological interests of one of the British Governor-generals, Lord Macaulay, resulted in an overemphasis on European literature and science at the expense of indigenous science and knowledge systems. All education was imparted in the English language which restricted democratic access of sciences by the masses.

Post-independence, there was a calculated emphasis on the spread of SE in India. SE was considered a harbinger of national development which would liberate citizens from irrationality and superstition (Agarkar, 2017). Article 51(A) of the Indian constitution states that one of the fundamental duties of every citizen is to 'develop the scientific temper, humanism and the spirit of inquiry and reform.' (http://www.constitution.org/cons/india/p4a51a.html).

It was coupled with unprecedented support for SE by the State. Huge amounts were invested in the setting up of research and development institutes like the Bhabha Atomic Research Centre, the Council of Scientific and Industrial Research, the Department of Atomic Energy, the Indian Space Research Organization, the Indian Medical Council, the Indian Council of Agricultural Research and premier higher education institutes like the Indian Institute of Technology, the Indian Institute of Science Education and Research, to name a few. Despite all these systematic endeavours, the impact of SE on the cultivation of scientific temper in the public at large has not been achieved (Sarukkai, 2014). Sarukkai further observed that Indian scientists, in spite of being good at their profession, observe unfounded religious practices, thus, indicating a dichotomy between their private and professional beliefs. Another common trend, according to him, is that students study science primarily for getting lucrative jobs without accepting the virtues of rationality, application of logic and reasoning, and the avoidance of bias and preconceived notions in arriving at decisions which are associated with the scientific ways of thinking. This scenario raises the following questions: Why is SE divorced from the public sphere? Why is the spirit of SE not taken up by the masses in India? Is the problem rooted in the state of school science education? The next section will probe the status of school science education to explore probable answers.

School Science Education

School science education, post-independence, was considered a pathway to instill scientific values and attitudes amongst youth (Agarkar, 2017). The National Council of Educational Research and Training (NCERT) was established to look into matters of education. It developed curriculum, and resources for education at all levels. Policy recommendations incessantly laid stress on SE. The Kothari Commission (1964–66) emphasised the compulsory teaching of science for the first ten years of schooling using an investigatory approach for all students (NCERT, 1970). Twenty years later, the National Policy on Education (1986) argued for the importance of science education for the country's economic growth and the development of a scientific temper among the masses (GOI, 1986).

While taking stock of the state of school SE, the National Curriculum Framework (NCERT, 2005) highlighted that, due to students not having opportunities to experience scientific phenomena during instruction, science learning has been reduced to a body of facts which is to be memorised and reproduced in examination situations. In fact, the National Policy on Education (NPE, 2016) categorically declares that poor performance in science and mathematics is the prime reason for high failure and dropout rates after formal end of year examinations occurring in Grade X. This state of affairs raises the following questions: Why, in spite of strong State support, students in India failing in science? What are the prime reasons for the experiential distancing of students in science classrooms? What has been done so far to make teaching-learning practices in science classrooms meaningful for students?

Sarangapnai (2014) argues that one of the prime reasons for the deplorable state of science education in schools, apart from lack of infrastructural facilities necessary to engage students with scientific practices (such as, laboratories), is the paucity of skilled teachers who possess the necessary pedagogical training. This training is provided in India by various teacher education programs, like the B.Ed. Many of these teachers are directly recruited into the school system after completion of Grade 12.

Although the statutory body governing teacher education in India, the National Council of Teacher Education (NCTE) makes it mandatory for teachers to have professional training through B.Ed. and other degrees, this rule is not consistently adhered to. This is because the demand for trained teachers burgeoned with the launch of the Right to Free and Compulsory Elementary Education (RTE, 2009) Act in April 2010. It made it an obligation of the government to ensure admission, attendance and completion of elementary education by all children in the 6–14 age group without being charged any kind of fee. Hence, an urgent need is to not only raise the number of teachers but also the quality of teachers entering the teaching profession (NPE, 2016).

However, the quality of science teaching undertaken by those teachers who have undertaken professional teacher training is no better than their untrained counterparts. It was noted by National Policy of Education (NPE, 2016) that, in order to meet the increasing demand for teachers, a large number of private universities and institutions providing teacher education have mushroomed all across the country. These 'teaching shops' are ill-equipped and operate with unqualified staff, often under the patronage of influential people who have little interest in education. This has resulted in a large group of trained professionals who are not fit to undertake innovations and match their teaching to the changing demands of the education system and society at large (NPE, 2016).

Even teachers graduating from premier teacher education programs often lack training in practice, for instance in performing science experiments. For instance, the B.Ed. program was so fast-paced during the reform period that, despite provision of space in the curriculum, there was no time to conduct experiments by pre-service teachers (Sarangapani, 2014).

The National Curriculum Framework of Teacher Education (NCFTE) notes that there is a dire need to upgrade the status of B.Ed. program which have outlived it's relevance in the twenty-first century (NCTE, 2009). Furthermore, the document identified that owing to structural and time constraints, one-year B.Ed. program has become weak both in theory and practice.

This recommendation spurred on the structural transformation of the time frame of the B.Ed. program from one-year to two-years, a key change in the history of teacher education in post-independence India. The new curriculum provides pre-service teachers opportunities to integrate ideas, experiences and professional skills through hands-on experience as they develop curriculum and learning materials, and design appropriate activities for children of different age groups.

B.Ed. Curricula Post-reform

The NCFTE (2009) observed that initial teacher education programs have a major role to play in the making of a teacher. These programs should be geared towards imbuing pre-service teachers with the knowledge-base and repertoire of pedagogical strategies essential for providing quality teaching. Following this realisation, India's teacher education underwent reform which culminated in a landmark revision, in the year 2015, of the curriculum, structure and organisation of one of India's teacher professional development programs, the B.Ed. This change embodied the current understanding of the needs and demands of India's science teachers and the school science curriculum, and it is hoped that it will lead to high-quality science education in Indian schools.

The new B.Ed. curriculum (NCTE, 2009), with specific reference to science education, offers a subject called 'Pedagogy of Science' in the first year of the program. This subject focuses upon developing the epistemological and pedagogical understanding of science as a discipline. It broadly comprises three areas: first, the nature of the school subject, including disciplinary knowledge and understanding of the social history of the subject in the school curriculum; secondly, the aims and pedagogical approaches for teaching of the subject at different stages of schooling; and thirdly, a deeper theoretical understanding of how children in diverse social contexts construct knowledge. This subject is assigned three hours of teaching per week and is followed by a 70 mark external examination towards the end of the academic year. An internal assessment of 30 marks requires pre-service teachers to write various assignments.

During the pedagogy lessons, which are conducted in the first year of the B.Ed. program, pre-service teachers are given opportunity to critically examine teaching and learning processes that incorporate inquiry, discovery, conceptual development and activity-based learning. They are encouraged to develop teaching-learning resources for various conceptual areas pertaining to the teaching of science during the school internship program to be happening in the concurrent year.

The School Internship program occurs for a period of 20 weeks in diverse school contexts—government and non-government (see Table 1)—where pre-service teachers are required to work like full-time teachers, participating in all school-related activities. This program is designed to lead to the development of a broad repertoire

Table 1 Types of schools

School type	Salient features
State-run/government	Managed by the State from the public funds collected through taxes. The State provides funding for faculty, student-related resources (e.g., school uniforms, curricular materials, stationery, meals to name a few), school building and other infrastructural facilities. Students in these schools are entitled to receiving free education and resources. These schools barely meet the basic requirements of hygiene and resources (Gupta, 2007)
Private/non-government	Managed by private bodies who charge students for their tuition and other facilities. They often have adequate and high-quality resources and infrastructure to support student learning (Gupta, 2007)

of perspectives, professional capacities, teacher dispositions, sensibilities and skills amongst pre-service teachers. Internship in schools includes an initial phase of one week for observing a regular classroom with a regular teacher, followed by teaching two school subjects for rest of the period. Other projects to be conducted during internship include peer observations, teacher observations and observations of pre-service teachers' lessons by faculty. Pre-service teachers are encouraged to write reflective journals during the internship programme and reflect on different aspects of their teaching experience and other school-related aspects.

Now, the question emerges as to how successful the new B.Ed. program is in developing the repertoire of content knowledge, and pedagogical competencies needed for teaching science among pre-service teachers. In order to develop an enhanced understanding of this issue, we employ the framework of pedagogical orientation as discussed in the next section.

Pedagogical Orientations and the Teaching of Science

Shulman (1986, 1987) coined the term pedagogical content knowledge (PCK) which includes knowledge of effective instructional practices pertinent to specific content areas. For science teaching, PCK must include understanding of 'scientific inquiry' (Lowery, 2002) and how to reflect and model scientific inquiry in science instruction.

Anderson and Smith (1987) coined the term 'orientation' and defined it as 'general patterns of thought and behaviour related to science teaching and learning' (p. 99). Magnusson, Krajcik, and Borko (1999) further theorised that teachers' pedagogical orientations were a component of PCK which provides teachers with a 'conceptual map that guides [their] instructional decisions such as daily objectives, the content of student assignments, the use of textbooks and other curricular material, and the evaluation of student learning' (p. 97). Thus, teachers' pedagogical orientations act as filters through which teachers selectively absorb specific purposes and goals for teaching science at a particular grade level (Abell, 2007; Friedrichsen et al., 2009). It was furhter identified in the above mentioned study that while enacting a set of orientations (or beliefs) into practice, teachers unconsciously merge their newly formed belief systems with their pre-existing belief systems, which were formed out of their own learning experiences as students of science. Thereby, teachers develop multiple belief systems towards teaching of science (Nargrund-Joshi, Rogers, & Akerson, 2011). Magnusson and her colleagues (1999) identified nine different science orientation: (1) process, (2) academic rigour, (3) didactic (4) conceptual change (5) activity driven (6) discovery (7) project based (8) inquiry and (9) guided inquiry.

Two themes have often been reported to influence a teacher's pedagogical orientation. One of these themes refers to external or contextual constraints that include physical learning environment (e.g., building structure and infrastructural resources), the human or cultural environment (e.g., student, parent and administrative expectations), and the political environment (e.g., policies and cultural norms) (Ford, 1992). The second theme refers to personal constraints such as a lack of understanding of the nature of science (Lederman, 2007).

Literature on teachers' science pedagogical orientations is plentiful across the globe, however, it is rarely studied in non-Western contexts (except, Zhang et al., 2003 in China; Ramnarain & Schuster, 2014 in South Africa, and Nargrund-Joshi, Rogers, & Akerson, 2011 in India). Moreover, pre-service teachers' pedagogical orientations have hardly been examined not sure in the Indian context, specifically, at a point of time when the country has seen a key change in teacher education policy and professional development curricula. Therefore, this study contributes to the research base, not only in understanding pre-service science teachers' orientations for teaching in non-Western contexts, but also in how contextual factors such as government policies and cultural traditions contribute to the development of their pedagogical orientations. These may impact our understanding of how to take a more global approach to teaching science.

Science Pedagogical Orientation Spectrum

In order to theoretically ground this work, this study uses the framework of 'science teaching orientation spectrum' developed at Western Michigan University by Schuster and Cobern (2011) and further pursued by Ramnarain and Schuster (2014). They suggested that teaching practices in science classrooms cover a wide spectrum ranging from didactic exposition to open inquiry learning. They considered four main orientations in the spectrum denoted as (A) didactic direct, (B) active direct, (C) guided inquiry and, (D) open inquiry. The first two practices are variants of direct instruction in which science is often presented as a body of facts by the teacher through direct instruction (ready-made science) while the remaining two are variants of inquiry-based instruction, in which a science topic is approached via scientific inquiry (science-in-making) with varying degree of guidance. In summary, the framework reflects two contrasting epistemologies, each with two common variants. The four approaches are further described in Table 2.

Table 2 Description of science teaching orientations

Science teaching orientation	Description
Didactic direct	Teacher presents the science concept or principle directly and explains it. Illustrates with an example or demonstration. No student activities only question-answer session
Active direct	Initially direct exposition, followed by student activity based on the presented science, e.g. hands-on practical verification of a law
Guided inquiry	Student exploration of a phenomenon or idea, with the teacher guiding them towards the desired science concept or principle arising from the activity. Teacher may explain further and give examples to consolidate
Open inquiry	Minimally guided by the teacher, students are free to explore a phenomenon or idea and devise their own ways of doing so. Teacher facilitates but does not prescribe

Goals of the Study

The specific focus of the study was understanding pre-service teachers' pedagogical orientations post-curricular reform in teacher education. However, it seemed crucial to understand the historical and educational policy context within which this study is placed. This need to examine the socio-cultural-policy context emerged from the understanding that educational practices are necessarily social actions embedded deeply in the context of that era. Keeping the importance of context in consideration, this chapter examines the historical development of science education in India, beginning with the policy context in pre-independence India to the present day, with a specific focus on school science education and teacher education.

Given the inquiry-based emphasis of the new teacher education curriculum and the enormous diversity in the schools where pre-service teachers go for their internship; it is important to assess the pedagogical orientations that teachers assume towards their classroom teaching after an internship; and, to identify factors which influence the same.

The following research goals guided the study:

- To investigate the pedagogical orientations of pre-service science teachers, completing the two-year teacher preparation program, B.Ed. in India, towards science classroom teaching;
- To probe how pre-service science teachers' pedagogical orientations vary with the genre of school in which they are placed during their internship;
- To determine what factors shape pre-service science teachers' pedagogical orientations towards science teaching.

Research Method

In order to situate the problem in the socio-cultural-political-historical context of the country, we used a comprehensive literature review (Onwuegbuzie & Frels, 2016) methodology. We systematically collected books, journal articles, policy documents, media reports and other documents available on the topic of science education in the country. The literature review began broadly with an intent to examine the status of science education in India. However, keeping in view the specific goals pursued with regards to pre-service teachers' pedagogical orientations, the literature review gradually tapered towards school science education and teacher education in the country. Themes emerging from the literature review were organised systematically to identify relationships among them which often led to a process of re-organisation of data, introduction or dropping of themes. The ideas emerging from the review are finally synthesised in this chapter to draw a vivid picture of the context through which the existing educational practices have come into being; and how different dimensions, namely, curricular reviews, educational vision in the policy documents, situational factors and others interplay with each other to give science education its' present shape in the Indian educational ecosystem.

To teach science effectively, one requires an integration of different types of knowledge, which includes knowledge of content, pedagogies, science teaching methods, inquiry, and how to apply these to teaching specific topics to specific groups of learners (Ramnarian & Schuster, 2014). In consonance with this view, any examination of teachers' science pedagogical orientations should be based on specific teaching scenarios where they get an opportunity to choose particular pedagogical approaches for teaching specific science topics. The test items used in this study were compiled from a collection of assessment items of this nature developed at Western Michigan University by Schuster et al. (2007), Schuster and Cobern (2011), and Schuster et al. (2012) and was named the Pedagogy of Science Teaching Test (POSTT).

The general structure of each assessment item is comprised of a classroom teaching vignette describing a realistic teaching situation for a particular topic, followed by a question which asks respondents to indicate how they would teach in that situation. Respondents have to make a choice from the set of options reflecting a set of four instructional types, namely, didactic direct, active direct, guided inquiry and open inquiry, and describe their reasons for making that choice. A selected response format was particularly suited to our purposes since it explicitly presents contrasting alternatives. Pedagogical preference items, provided as options to the classroom vignettes, may look like conventional 'multiple choice questions', however, there is no single 'correct' answer or 'wrong' distracters; rather, the options offer alternative teaching approaches, whose character is consistent across items, for respondents to indicate their preference. The nature of this new kind of pedagogy assessment is best illustrated by an example provided in Fig. 1.

This item involves alternative approaches for teaching-learning laws of flotation. The item consists of vignette, question, response options and space to write reasons.

Sink or Float

Ms. Hema has her students gather around a small pool of water. She has a set of objects of different sizes and different materials; some will sink and some will float. Ms. Hema's goal is for her students to first distinguish the objects by whether they sink or float, and then realize that this does not depend on the size of the object but on what it is made of (e.g., the stones will all sink no matter how big or small they are, and the wooden blocks will all float).

Thinking of how you would teach this lesson, of the following, what would you most likely do?

- Drop objects one by one into the water, and have the children notice that some sink and some float. Point out that all the stones sank, no matter how big or small, and all the wooden blocks floated, etc. Conclude by stating the lesson objective that it is not size that matters but the material the object is made of.
- Have students come one by one and drop an object into the water, with everyone calling out whether it sank or floated. Point out that all the stones sank, no matter how big or small, and all the wooden blocks floated, etc. Conclude with the lesson objective, that it is not size that matters but the material the object is made of.
- Have students come by one by one and drop an object into the water, with everyone calling out whether it sank or floated. Ask them to suggest what this depended on; when some suggest size and others what it is made of, have them test these ideas by dropping more objects. Then have them agree on a conclusion.
- Have all the students drop various objects in the water and seeing what happens. Then have them talk among themselves about this and ask volunteers to give their ideas about it, with others saying if they agreed or not.

Fig. 1 Example assessment items

Note that for illustrative purposes, the options in the above example are presented in 'spectrum' order: didactic direct, active direct, guided inquiry and open inquiry, while in practice, the options were ordered randomly.

Thirty-one pedagogy items were selected from suitable earlier Pedagogy of Science Teaching Test (POSTT) items. The POSTT consists of twenty-one items from physical sciences and ten from biological sciences. This compilation in the form of an instrument appropriate for Indian context was named POSTT-India. The curriculum appropriateness of the chosen items for the Indian curriculum and context was investigated by a panel of one Indian science education researcher and one in-service school teacher who had been teaching middle-grade science in the Indian school context for more than fifteen years. The panel established that all item vignettes were on science topics taught in the Indian school curriculum. Panellists also classified, individually, the options for each item into four intended pedagogical orientations. There was 100% agreement on the classification, and this also confirmed the validity of the orientations specified by the developers for the response options. The instrument was piloted with twenty pre-service teachers, and interviews with these teachers on the readability and clarity of items resulted in minor modifications.

Adopting a 'sequential explanatory mixed methods' design (Creswell, 2003) which enables the researcher to 'collect both quantitative and qualitative data, merge the data, and use the results to best understand a research problem' (p. 564), quantitative data collected in the first phase, was followed by the collection and analysis of qualitative data in a second phase that builds on results of the initial quantitative results.

Data Collection Procedures

POSTT Instrument and Questionnaire Administration

Quantitative data were collected by means of the POSTT—India instrument to examine the pedagogical orientation towards science teaching of seventy pre-service teachers teaching Grade 6–8 in a cosmopolitan city of India. This study was conducted with the first cohort of pre-service teachers who were going to graduate from the new B.Ed. program post-reform in the year 2017.

Focussed Group Discussions

Five sessions of focussed group discussions (FGDs) were carried out with teachers who had responded to the questionnaire. The group size varied between 10 and 15. Half of the teachers in each group belonged to the State-funded government schools, while the other half belonged to private schools. The theme of FGDs entailed detailed discussion of the pedagogical choices teachers made in response to each item, as well as why other options were not chosen. Discussions ensued on the situational factors that promoted or inhibited choice of particular pedagogical approach.

An assistant researcher was contracted to take detailed field notes of FGDs which were later transcribed verbatim. In addition, during all these sessions, teachers were asked to write reflective notes describing the primary reasons behind their pedagogical orientations towards science teaching. Further, one of the researchers observed the science classrooms of a group of six pre-service teachers as a regular mentor while she observed other pre-service teachers' science classrooms on a rotational basis. Field notes and reflections garnered from these classroom observations substantiated the findings.

Data Analysis Procedures

Quantitative Data

The data was analysed using MS-Excel. An example representing the choices made on the POSTT-India Item in Fig. 1 is shown in Fig. 2. Further, comprehensive analysis of all responses for all items and participants will be provided in a journal article to follow.

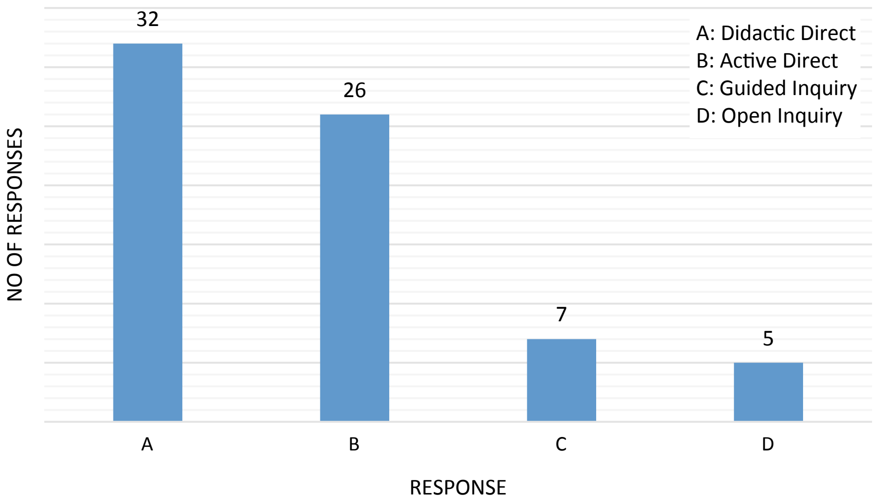

Fig. 2 Response choices on POSTT item provided in Fig. 1. *Note* A strong orientation of teachers toward direct instruction methods rather than inquiry for this item emerges, despite the fact that guided inquiry-based methods are now advocated in India for science teaching. Several reasons for this preference in the real teaching situation became clear from the survey and teacher interviews, as described below in the qualitative part of the study in the next section

Qualitative Data

Qualitative data collected by means of focussed group discussions, teacher interviews, classroom observations, and pre-service teachers' reflective notes were recorded and transcribed. The data was then coded and classified, a process that involved breaking up data into bits and bringing it together again in a new way (O'Donoghue, 2007). We firstly did an open coding of data, looking for reasons that could explain the options chosen. We then grouped the codes into code families.

Results

This section discusses the major themes, emerging from qualitative analysis of the data and further substantiated by quantitative results, which were found to influence pre-service teachers' pedagogical orientations.

School Related Factors

School culture seemingly created a 'figured world' (Holland, Lachicotte, Skinner, & Cain, 1998) through which the school's philosophy, vision and mission were communicated implicitly to pre-service teachers which, in turn, influenced their pedagogical orientations. Schools observed for the study had a variety of philosophical orientations vis-à-vis science teaching, ranging from inquiry-orientation to didactic teaching. Some of the school-related factors that influenced classroom practices are detailed below:

School Culture

Pre-service teachers were influenced by the implicit expressions of school culture and planned their lessons accordingly. To illustrate, in schools where a culture of scientific inquiry was already in place pre-service teachers felt motivated to adopt inquiry-based pedagogical approaches. They noted

> Students are so used to doing it themselves (referring to science activities), asking questions, performing activities….and all those inquiry stuff, I have to plan my lessons accordingly….

Mostly, pre-service teachers in private schools had to deal with highly inquisitive students. These students had exposure to varied forms of knowledge through out-of-the-box tasks developed by their regular school teachers, easy access to internet resources both at home and at school. Pre-service teachers teaching in private schools observed

> They ask too many questions which hinders the way I had planned the lesson
>
> Their questions are nonsensical at times, they just ask to trouble me…if I say later or I don't know they start laughing at me….
>
> … to satiate their queries I have to be prepared with lots of scientific content…
>
> Students provided lots of examples…it ranged from India to abroad….it enriched my knowledge as well….

Pre-service teachers placed in private schools had to plan their lessons innovatively in order to hook students' attention so that they felt motivated to engage with science.

Factors which contributed to inquiry-based scientific practices in these schools included systemic support, in-house professional development opportunities provided to the teachers, regular workshops, seminars and lectures for teachers, time provided for teachers to access the school library during their regular timetable hours, active school-based professional learning communities, support in science lesson planning provided by senior teachers to junior faculty and new recruits, and peer observation of classroom teaching by colleagues and experts. While situated amongst such contextual factors, pre-service teachers felt encouraged to plan and deliver scientific inquiry-based lesson plans. In such schools, it was observed that pre-service teachers were supported by school faculty to adapt to inquiry methods through constant academic as well as non-academic support.

On the other hand, pre-service teachers placed in Government schools (although exceptions existed) observed that students were so accustomed to unquestioning obedience to the teachers and the textbook that they never raised questions. Some of the teachers placed in government schools explained their views as follows:

> It was difficult for me to gauge whether whatever science I was trying to develop is being understood by them or not….they will neither ask nor they will answer. Only one student may say few things now and then…
>
> It's not like they are dumb…but they don't speak up…I pushed them so much, it seemed initially that they had no view of their own…however, later things began changing in my class. They started asking questions, providing arguments and counter-arguments…it was very slow…what I did was I deliberately planned a component of active direct to guided inquiry for them in some form or the other…it was very basic stuff that they could do at their houses, such as, planting a tree and measuring its' growth, examining bread mould in different conditions, examining rate of decay of a banana and comparing it with that of apple, and so on….

Teachers teaching in schools where a culture of silence existed found it difficult to engage large numbers of students in inquiry-based science teaching.

Availability of Resources

Resources, both in terms of quality and quantity, differed in government and private schools. Moreover, their access was limited in some scenarios which eventually limited their usage by pre-service teachers in their pedagogical planning.

Government schools often faced a scarcity of resources. To elaborate, in one government school, there was no science laboratory while in other it was used to dump waste, and in yet another case, where it existed and was functional, it emerged that the infrastructure was too limited to accommodate the class size. As a consequence, the class was divided into two groups- 'good and bad' students. Only 'good' students (referring to students who were high academic achievers in formal tests) performed experiments while 'bad' (low-achievers) ones were made to sit in their classrooms.

Pre-service teachers placed in government schools noted that they often prepared their lesson plans around scientific inquiry but a lot of it got lost when it came to execution. They noted that owing to *large class sizes* which in some cases went up to 70 students per class, teachers found themselves helpless to engage students even in guided inquiry. In government schools, many mergers of classes occurred due to frequent teacher absences or teachers being engaged in completion of the school's administrative work. In such scenarios, pre-service teachers survived by dictating notes or performing demonstrations to make students sit quietly. One teacher placed in a government school noted:

> Demonstrations work as a better option. At least there is something visual for students to connect to…

To which another teacher teaching in another government school added,

> I find even demonstrations difficult, unnnn….you see the other day I wanted to show them how different materials get attracted to magnet, attraction and repulsion between different poles of two bar magnets,…. I had the necessary stuff and my classroom had only 45 students that day…but the space is so cramped…they all had to jump over each other to see what I was doing….I decided to move between rows of seats but I was almost falling down…so after showing it once…I just passed the material….my entire class time got finished in this…I couldn't discuss the scientific content or their observations from the materials….

Similar observations were reiterated by another teacher who was placed in a private school:

> This is not unique to you…I mean I am placed in a private school but classroom spaces which were constructed for 40 students now seat 50 students …they have placed additional benches but it leaves no space for me to move around …I eventually end up doing the stuff you just mentioned…

Cramped *classroom spaces* coupled with paucity of resources lead teachers to abandon inquiry midway.

Pre-service teachers noted that private schools often have smart boards in each and every classroom with pre-installed software on different science topics. This software and internet access helped in raising curiosity among the learners, thus, paving a way to enriching classroom discussions. In such an atmosphere, it was easy for pre-service teachers to plan and execute inquiry-based science activities.

On the other hand, government schools didn't have any *ICT based tools* in their classrooms. In some of the schools, there was one projector for the entire school. Computers did not have any internet access. In these school scenarios, pre-service teachers made charts, flannel boards, flash cards, etc. for their lessons. They observed

> Bringing materials for all the students in the class to conduct inquiry based activities is very expensive….

Eventually, in the face of these troubles, they usually abandoned inquiry-based science education.

Time was another important resource for pre-service teachers. Government schools were centrally managed by the Ministry of Human Resource and Development, Government of India. Curricular planning was done beforehand by external authorities. All the schools were made to complete a particular quantum of syllabus in specific periods of time. Any change is not permitted. Therefore, pre-service teachers were not allowed to try out different ways of teaching, rather it was expected that the teachers complete the course by reading the chapter and dictating/guiding students to do textbook questions in their notebooks. Government schools lay strong emphasis upon finishing the curriculum by making students memorise a few fact-oriented questions that had a high probability of coming up in the summative examinations. Pre-service teachers noted that anything other than textbook reading was considered fancy and irrelevant by the teachers and school administration. One of them observed

> My school principal constantly made complaints regarding my ways of teaching to my supervisor. They (referring to both school administration and regular school faculty) pressurised us to finish the syllabus and do revision instead of wasting time in inquiry based activities.

To which another pre-service teacher added:

> Regular teachers consider us as 'substitutes'…. I mea(n)… who could teach while they finish their administrative tasks. I am not left with any time to plan my lessons, gather materials from school laboratory etc. for conducting inquiry…you see…as all my periods are occupied….

However, this was not the case in private schools. A pre-service teacher placed in a private school observed:

> We (referring to her the group of 6 student interns who were placed in the same school) were given ample time to cover topics. We generally get topics, like, water, waste management, pollution….where lots of discussion could take place…there is no time boundation…we felt free to discuss and develop it in our own ways…

Time to explore a variety of pedagogical approaches helped them to evolve as science teachers.

Medium of Instruction

Pre-service teachers placed in government schools were made to teach science in Hindi. They reported:

> …it is difficult to teach science in Hindi as I tend to forget the technical terms…and its' pronunciation is like a tongue twister….

Another teacher added

> I have had all my education in English medium…now teaching science in Hindi is the toughest challenge of PD…
>
> I find it difficult to write in Hindi ….to be true…sometimes I use wrong terms….but students correct me…they can understand my difficulty….

As per classroom observations, it was found that most of the pre-service teachers taught science in English despite the fact that students had textbooks in Hindi and had opted to write their examination in Hindi. This is largely due to their own comfort levels in teaching science in English. They argued that English is the language of global discourse. One of them observed:

> In case, these students opt for Science in higher education, they will in any case have to study the subject in English language, so it is better to start right away…

Students were somehow able to manage as in-service teachers code switched from Hindi to English and vice versa. On the other hand, pre-service teachers who have had their own education of science in Hindi were found to be adept in teaching science in the Hindi language.

Resistance to Inquiry

It was observed that a few schools offered resistance to the change of their routine ways of teaching. At times, when pre-service teachers adopted scientific inquiry to which students responded positively, in-service school teachers forced them to abandon these activities for fear of these students getting a taste for inquiry, and hence, not respecting their didactic ways of teaching. In-service teachers posed problems for pre-service teachers such as: barging into the classroom in the midst of a lesson; not allowing the pre-service teacher to take the periods assigned for teaching. Cultural resistance forced pre-service teachers to shun inquiry and adopt didactic methods.

These views indicate that schools expect pre-service teachers to assimilate their routine ways of working. Anything that challenges the popular beliefs of the cultural context of school is rejected by most of the stakeholders.

Discrepancy Between Professional Development Program Orientation and School-Related Factors

The situational factors discussed in the last section led to conflicts between what was expected in the professional development program in terms of inquiry-based lesson planning and how teachers enacted their plans in the school situations. They observed that school-related factors, such as stress on summative assessments, classroom management and so on made them teach in didactic ways. One of them observed:

> My supervisor (referring to the faculty attached as mentor through PD program) insists on making an inquiry based lesson plan …she will cut my marks if I don't do that…but that plan is obsolete in the school situation…I have to rework the stuff to make it deliverable in my classroom context…And…. I do it by changing all the student-centred activities to teacher-led demonstrations….I mean….she is not coming everyday to observe me …. and, I have to teach them anyhow…they should know the content otherwise they will fail.

Another teacher added:

> I need to learn how to swim in the ocean where I am thrown….my supervisor will not come to teach here….All those fancy words taught to us in Pedagogy paper (referring to Pedagogy of Science paper taught to pre-service teachers during first year of B.Ed.) are not going to help me….In order to maintain structure, I dictate notes to them, this makes all the parties (referring to stakeholders- students, teachers, parents, and school principal) happy…

These ideas indicated that pre-service teachers were unable to execute their actual lesson plans—often based on principles of inquiry-based science teaching—in the face of situational factors emerging from the school context. To resolve this issue, they made two plans for the same content: one that was inquiry-based and that served the requirements of the teacher education program; and the second which was based on didactic transmission of information to fit into the school context.

Pre-service teachers suggested that they tried to communicate and convince their supervisors (faculty from teacher education program associated with them as mentors) regarding the situational factors but to no avail. Supervisors did not appreciate their problems and insisted upon inquiry-based lesson plans using a variety of methodologies. One of the pre-service teachers noted:

> I tried to tell her many times that the inquiry based science projects you want me to do are simply irrational for schools like this…but she is not ready to accept it…and all her ideas of doing low-cost no-cost science is very difficult to execute….umnnn…. I won't be able to do it with such large numbers…hmm…but in 'ideal' conditions…. I would love to execute my actual plans and see how scientific inquiry looks into practice.

Pre-service teachers' views constantly alluded to the importance of mentor support in development of their pedagogical orientations. Further probing in this direction suggested that they preferred mentors who could suggest ways of doing inquiry rather than simply writing comments about their didactic pedagogical approaches.

Teachers' Belief About Science and Pedagogy

Apart from situational factors, it was apparent that teachers did not have a clear understanding about the various ways in which scientific inquiry could be practiced.

Skewed Version of Scientific Inquiry

Pre-service teachers used a variety of teaching-learning materials to develop scientific concepts. They noted

> I, at least, show them charts, models, or at times, videos… you can see my students are so happy …whenever I take material for demos (referring to demonstrations)…they are excited, they don't make noise and all of them behave well so that they get to see it…

Another teacher teaching in another government school added,

> I invite few representative students to do it….they all want to touch stuff…work on things….but I can't afford all of them to be a part of it…so I do it on rotation basis …

These viewpoints suggest that teachers considered the transmission of scientific information through varied teaching-learning materials to be the same as scientific inquiry. There was an inherent understanding that showing videos, charts, or models is equivalent to scientific inquiry. Pre-service teachers placed in government schools complained that their counterparts, who are teaching in private schools, have easy access to ICT based tools and had smart boards with pre-loaded lessons installed in it. According to them, having smart boards is a great help as it enables making links between the content and world outside. While this sounds true, how the use of these tools relates to scientific inquiry remained a question which was unanswered.

Belief About Students

It emerged that many of the teachers who opted for didactic pedagogy did it consistently across a number of POSTT items. Upon further probing, it was observed that their reasons behind these choices were that they had an intrinsic belief that students belonging to low socio-economic class are inherently incompetent in pursuing scientific inquiry, thus, flagging a nativist view of human intelligence. They thus considered it imperative to 'tell' the scientific content to students belonging to low socio-economic groups. When asked whether they were taught such a view in their teacher education programs, pre-service teachers during focussed group discussions observed,

> …..fancy stuff told in B.Ed. does not work in reality…

Another dimension of pre-service teachers' belief systems that seemingly influenced their pedagogical choices was the relationship between inquiry-based science education and student academic achievement. They noted that often high achieving students possess high cognitive abilities, hence, they adopted didactic pedagogy for *Nishtha* (group of low-achievers), and inquiry-based science instruction for *Pratibha* (group of high-achievers).

Teachers' Competence in Handling Inquiry

Almost all the teachers agreed that science teaching through inquiry was very challenging. They were scared of students' questions which they were unable to answer instantly. One of the teachers noted:

> Unnn…they will stop respecting me if I say 'I don't know'.

To which other teachers added:

> In our scenario, things are even more challenging. Students have access to large reservoirs of information through tuitions, internet….their parents are also educated…they ask questions to trouble us…if I say I don't know they will mock at me…I will be gone…

> Ya right…I can't answer everything spontaneously…they are always full of questions because we give them space… unlike their regular teachers…. where it is simply impossible to speak…

These ideas suggest that teachers are not adequately prepared to handle inquiry. Their position as a 'trainee teacher' made them even more vulnerable. In another focussed group discussion, a teacher who had taught in a private school observed:

> It takes time to win the trust of students… once they start accepting you then they will listen to you, appreciate your humility when you say "I don't know, let's find together"…It took me time but somehow my consistency, may be…I am not sure, helped me in establishing a culture of inquiry in my classroom.

They felt incompetent to answer queries and felt the need to update their content knowledge.

Success Stories

It emerged that in spite of discrepancies between what was taught in the B.Ed. program and what was being practiced in schools, there were cases where a few motivated teachers adopted scientific inquiry in their respective contexts. One of the teachers teaching in a government school observed:

> India has got a tradition of low-cost science, see what is being done by our Toymaker, ….I mean…Arvind Gupta…, for long now…I am also placed in a government school which has large class size of 50, no functional lab (referring to laboratories) for me to conduct experiments …but that doesn't mean that they should be marooned from the experience of scientific inquiry…Umnn…open inquiry is I feel impossible but doing some guided inquiry could certainly happen. Ok, what I do is… I have given them an inquiry-based science project to be conducted through my period of work here…They will have to choose a topic for the same, inform me rather (emphasis in voice) consult me, we devise a plan of action and …. they will have to perform it themselves…..It is important for me to make it workable, that is, the apparatus should not be fancy enough…I mean things which are around …could somehow be used… we could find an alternative…. It is not necessary that inquiry based tasks always belong to the content that I am teaching but my intention is to develop scientific processes in them…

This view indicates that scientific inquiry is not always content-specific. Rather, a few motivated teachers deployed inquiry-based pedagogical approaches irrespective of the content they were teaching.

Teachers observed that initially students used to find fault with their ways of teaching, in fact, they reported it to school authorities that they were doing bad teaching. But later things changed. This observation was corroborated by other teachers as well. They stated that

> it happened with all of us but gradually students found our ways of teaching exciting. They did the work we designated with great enthusiasm. It was so invigorating for me as a teacher.

One of them noted

> I had asked them to collect leaves of different shapes and sizes from in and around their community. Next day, everyone had brought it. They were eager to know how we are going to use it. When I assigned them the task of classification of leaves, they did it earnestly, I was so happy…they were able to make connections between different types of venation taught to them in the theory class…

Conclusion

It emerges that teachers began their internship journeys enthusiastically, armed with inquiry-based pedagogical approaches. However, situational constraints led to amendments in their practice. Similar to Nargund-Joshi, Rogers, and Akerson's study (2011), it was found that situational factors, such as, availability of ICT based tools, science laboratories, time for pedagogic planning, classroom space, teacher-student ratios, medium of instruction and resistance to inquiry acted as filters which, at times, facilitated the inquiry-based science teaching approaches while in other cases acted as barriers making them adopt didactic ways of science teaching. Pre-service teachers devised their own unique ways to handle the tensions and discrepancies between what was taught to them and expected of them by their teacher education programs and what was feasible in the school context. They made dual lesson plans: one as per the requirements of PD program and other suiting the school context.

School culture created a figured world which subtly influenced teachers' belief systems—about science as a discipline, about children's cognitive abilities, and about scientific inquiry. Mostly, it was found that in private schools curricular and pedagogic practices supported scientific inquiry while in government schools didactic instruction worked best. However, this is not the uniform case and variations occurred across the spectrum.

Teachers' pedagogical orientations were also influenced by their personality attributes, as a few teachers persisted in practicing scientific inquiry despite situational constraints. These pre-service teachers not only placed high value on scientific inquiry but also possessed the competencies necessary to conduct scientific inquiry in its true spirit, unlike others who abandoned inquiry-based science instruction owing to their skewed understanding of scientific inquiry.

Teacher education can only work towards expansion of teachers' skill repertoire but it cannot guarantee the same in practice. Teachers' pedagogical orientations are strongly dependent upon the school type that they are placed in as interns and how these situational factors engage with their belief systems, as well as the degree to which they possess competencies to conduct scientific inquiry. Therefore, it can be suggested that pre-service teachers' pedagogical orientations were an amalgamation of science teaching philosophies taught in professional development, their own experiences of science learning as a student, and what seemed to work best in varying school situations where they were placed as interns during their professional development programs.

References

Abell, S. K. (2007). Research on science teacher knowledge. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 1105–1150). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Agarkar, S. C. (2017). Science education for national development: Indian perspective. In B. Akpan (Ed.), *Science education: A global perspective* (pp. 107–124). Switzerland: Springer.

Anderson, C. W., & Smith, E. L. (1987). Teaching science. In V. Richardson-Koehler (Ed.), *Educators' handbook: A research perspective* (pp. 84–111). New York: Longman.

Bryan, L., & Abell, S. (1999). The development of professional knowledge in learning to teach elementary science. *Journal of Research in Science Teaching, 36,* 121–140.

Children's Right to Free and Compulsory Education Act. (2009). http://mhrd.gov.in/sites/upload_files/mhrd/files/free_and_compulsory_NEW.pdf.

Creswell, J. W. (2003). *Research design: Quantitative, qualitative, and mixed methods approaches*. Thousand Oaks: Sage.

Ford, M. E. (1992). *Motivating humans: Goals, emotions and personal agency beliefs*. Newbury Park, CA: Sage.

Friedrichsen, P. J., Abell, S. K., Pareja, E. M., Brown, P. L., Lankford, D. M., & Volkmann, M. J. (2009). Does teaching experience matter? Examining biology teachers' prior knowledge for teaching in and alternative certification program. *Journal of Research in Science Teaching, 46*, 357–383.

Friedrichsen, P. J., Van Driel, J. H., & Abell, S. K. (2011). Taking a closer look at science teaching orientations. *Science Education, 95,* 358–376.

Government of India (GOI). (1986). *National policy on education.* Ministry of Human Resource Development. Department of Education: India. Retrieved from http://mhrd.gov.in/sites/upload_files/mhrd/files/NPE86-mod92.pdf.

Government of India (GOI), Ministry of Human Resource Development. (2016). *National policy on education 2016*. Report of the Committee for Evolution of the New Education Policy. Available from http://www.nuepa.org/New/download/NEP2016/ReportNEP.pdf.

Gupta, A. (2007). Introduction: Culture, curriculum, and points of intersection. In A. Gupta (Ed.), *Going to school in South Asia* (pp. 1–14). Westport, CT: Greenwood Press.

Holland, D., Lachicotte, W., Jr., Skinner, D., & Cain, C. (1998). *Identity and agency in cultural worlds*. Cambridge: Harvard University Press.

Lederman, N. G. (2007). Nature of science: Past, present, and future. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research in science education* (pp. 831–879). Mahwah, NJ: Lawrence Erlbaum Associates.

Lowery, L. F. (2002). The nature of inquiry. *Science Link, 13*(1), 3.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95–132). Dordrecht: Kluwer.

National Council of Educational Research and Training (NCERT). (1970). *Education and national development: Report of the Education Commission 1964–66.* (D. S. Kothari: Chairman). New Delhi: NCERT.

National Council of Educational Research and Training (NCERT). (2005). *National curriculum framework* (NCF-2005). Available from http://www.ncert.nic.in/html/pdf/schoolcurriculum/framework05/prelims.pdf.

National Council of Teacher Education (NCTE). (2009). *National framework of teacher education: Towards preparing professional and humane teacher* (NCFTE). Available from http://ncte-india.org/ncte_new/pdf/NCFTE_2010.pdf.

Nargund-Joshi, V., Rogers, M. A. P., & Akerson, V. L. (2011). Exploring Indian secondary teachers' orientations and practice for teaching science in an era of reform. *Journal of Research in Science Teaching, 48*(6), 624–647. https://doi.org/10.1002/tea.20429.

O'Donoghue, T. (2007). *Planning your qualitative research project: An introduction to interpretivist research in education*. London and New York: Routledge.
Onwuegbuzie, A. J., & Frels, R. (2016). *Seven steps to a comprehensive literature review: A multimodal and cultural approach*. USA: Sage.
Ramnarain, U., & Schuster, D. (2014). The pedagogical orientation of South African physical science teachers towards inquiry or direct instructional approaches. *Research in Science Education, 44*, 627–650.
Sangwan, S. (1990). Science education in India under colonial constraints, 1792–1857. *Oxford Review of Education, 16*(1), 81–95.
Sarangapani, P. M. (2014). Three challenges facing Indian school science education. Essays *science education: Few takers for innovation.* Mumbai: IKF (IRIS Knowledge Foundation). Accessed from http://www.esocialsciences.org/eSS_essay/eSS_Essay_Science_Education.aspx.
Sarukkai, S. (2014). Indian experiences with science: Considerations for history, philosophy, and science education. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching* (pp. 1691–1717). Dordrecht: Springer. https://doi.org/10.1007/978-94-007-7654-8_53.
Schuster, D., & Cobern, W. W. (2011). Assessing pedagogical content knowledge of inquiry science instruction. In *Proceedings of the International Conference of the National Association for Research in Science Teaching*, Orlando, FL, USA.
Schuster, D., Cobern, W. W., Adams, B., Skjod, B. A., Bentz, A., & Sparks, K. (2012). Case-based assessment of science teaching orientations. In *American Educational Research Association National Conference*, Vancouver, British Columbia, Canada.
Schuster, D., Cobern, W. W., Applegate, B., Schwartz, R., Vellom, P., Undrieu, A., & Adams, B. (2007). Assessing pedagogical content knowledge of inquiry science teaching—Developing an assessment instrument to support the undergraduate preparation of elementary teachers to teach science as inquiry. In *Proceedings of the National STEM Assessment Conference*, National Science Foundation and Drury University, Washington DC. Published by Drury University.
Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15,* 4–14.
Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57,* 1–22.
Zhang, B., Krajcik, J., Sutherland, L. M., Wang, L., Wu, J., & Qiang, Y. (2003). Opportunities and challenges of China's inquiry-based education reform in middle and high school: Perspectives of science teachers and teacher educators. *International Journal of Science and Mathematics Education, 1,* 477–503.

A Comparative Case Study of Primary Science Teachers' Beliefs and Orientations

Vanashri Nargund-Joshi, Meredith Park Rogers and Deepali Bhagwate

Abstract This chapter presents a comparative case study of the concepts and behaviours, otherwise referred to as *orientations*, of two primary science teachers. We have utilised a theoretical framework of Pedagogical Content Knowledge (PCK). Differences in teachers' orientations according to school types (public versus private) are examined to further understand how contextual factors may influence this alignment with practice. To assist with this understanding, profiles of teachers are presented depicting their science teaching orientations based on interviews with each teacher and several observations of their teaching. These profiles provide a point of reference for understanding the kinds of orientations these teachers hold for teaching science. We analysed the teachers' orientations along a continuum from traditionalist in nature to inquiry/constructivist in nature. The analysis of teachers' orientations led us to suggest that teacher(s) had partial knowledge regarding students' scientific thinking, curriculum design, instructional strategies, and assessment. Several contextual factors contributed to teachers' orientations, including environmental constraints, such as limited resources and large class sizes, pressures from a cultural of testing, and limited access to professional development. We conclude the chapter with implications for various stakeholders. We also provide suggestions for future research to understand the complex interaction between teachers' orientations, PCK and the overall support available in a classroom for a teacher.

Introduction

Pedagogical Content Knowledge (PCK) (Shulman, 1986) is often referred to throughout the literature as 'specialised knowledge' that teachers have, thus differentiating

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the content knowledge that they possess from the content knowledge of experts. PCK has served as a catalyst for considering the ways in which teachers need to think about the subjects they teach. Shulman (1986) defined PCK as ‘subject matter knowledge for teaching’ and as ‘the ways of representing and formulating a subject that make it comprehensible to others’ (p. 9). Shulman (1987) stated that ‘[PCK] represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organised, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction’ (p. 8). This means that understanding teacher’s PCK allows us to look into the teacher’s thought processes to see how he or she blends knowledge of different aspects of teaching in order to make instructional decisions. It includes knowledge of how topics, problems, and issues in a particular subject can be organised, represented, and adapted to accommodate the diverse interests and abilities of learners, and then presented for instruction.

For this study, we situate PCK within the ideas outlined in Magnusson, Krajcik, and Borko’s (1999) framework, but specifically reference Friedrichsen et al. (2009) version of this model (see Fig. 1). We have elected to follow the Friedrichsen et al. (2009) model because they demonstrate how the component of teaching orientation acts as a filter for decision-making in all of the other knowledge components. In addition, their model illustrates how knowledge of context plays an integral role and serves as a potential influence on one’s PCK.

They say that, although PCK is an amalgam of all the components of teacher knowledge, it is essential to focus on each component individually in order to develop PCK to the fullest. As part of this, it is also important to focus on orientations as a

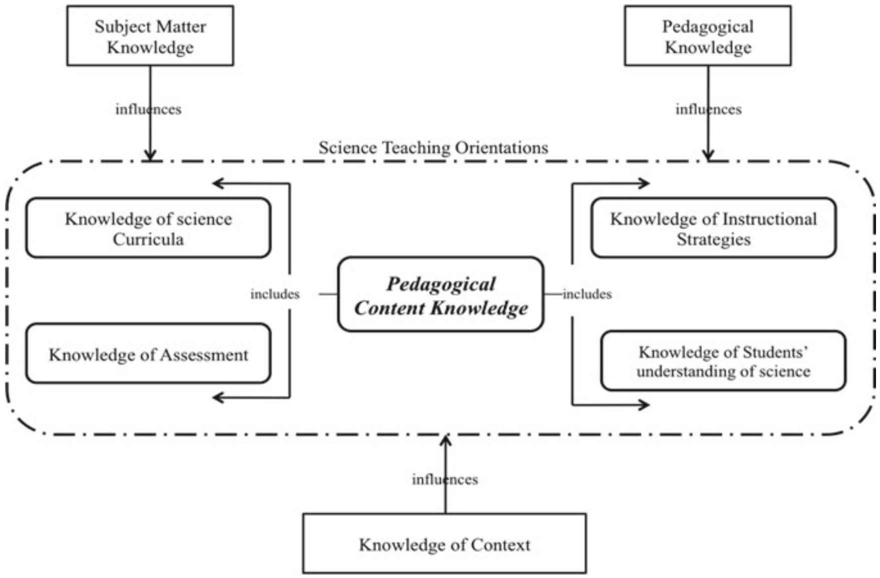

Fig. 1 Theoretical framework of knowledge for teaching (Friedrichsen et al. 2009)

Table 1 Reshuffling of orientations for science teaching to be used in this study

Orientation	Traditional	Activity	Conceptual change	Inquiry
Characteristic of instruction	Teacher focuses more on covering large amount of syllabus and focus is more on memorising higher-level concepts than understanding them	Teacher performs activities and demonstrations in the classroom or laboratories but focus might not be on conceptual change	Teacher focuses on developing students' understanding about a concept and connect it to their lives	Teacher focuses on developing students' understanding of scientific concepts as well development of skills. Teacher guides students' learning and lead them towards open-ended inquiry

central component to understanding all the variations in a teachers' knowledge-base of the other components. This central or core view of the influence of orientation on the entire PCK framework aligns with our view of how a teacher's 'specialised knowledge' is formed and thus this view anchors our study, which more specifically focuses on orientations toward science teaching.

The concept of orientation has been referred to as a 'messy construct' in science education literature because researchers either have provided no clear definition, or have introduced a new term into the mix (Friedrichsen & Dana, 2003). This study utilises a definition by Anderson and Smith (1987) which describes orientation as 'general patterns of thought and behaviour related to science teaching and learning' (p. 99). At the time of this study, the following nine orientations were often referred to in order to identify how teachers approached their planning and instruction. They are (1) Academic, (2) Didactic, (3) Activity Driven, (4) Process, (5) Project Based, (6) Conceptual change, (7) Inquiry, (8) Guided inquiry, and (9) Discovery.

However, some of the critiques of the construct of orientation suggest that it is a 'quick fix', instead of focusing on understanding the complex nature of orientation, and 'pigeon holes' teachers, since most of the teachers hold more than one orientation (Friedrichsen, van Driel, & Abell, 2011). Hence, we shuffled the nine orientations into four main categories (Table 1) to represent teachers' orientations more realistically.

Methods

This study follows a qualitative research approach framed by a case study design and an interpretive orientation of the data (Merriam, 1998, 2009). A case study approach allowed us to gather a broader understanding of Indian teachers' orientations for teaching science at different grade levels and in different school environments in order to determine if there is any variance in contextual factors influencing the teachers' orientations. Yin (2002) defines a case study as 'an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident' (p. 13). The nature of orientations in the PCK framework makes a case study framework suitable for the study. Though orientations are situated as a central component of the PCK framework, the boundaries between orientations and other knowledge components are often blurred and should not be compartmentalised. Based on the purpose of this study, following research questions were crafted to guide the study:

1. What science teaching orientations do these two Indian teachers exhibit?
2. What factors contribute to and/or influence the development and implementation of these orientations? Do these factors differ according to type of school within the Indian context?

Description of Context and Participants

This study was carried out in an urban setting in the Western state of Maharashtra in India. Participating schools included two private and two government schools. Primary and middle school grades were held in one building and secondary grades in a separate building for both types of schools. All schools followed the Maharashtra school board syllabus. In the two private schools, instruction was in English across all grade levels. However, in the two public schools only primary and middle school grades were taught in English, and the secondary school used the native language of Marathi as a medium of instruction. Both private and government schools had a large number of students in each grade level. Therefore, students were divided into different classes, much like schools in the U.S., and the average number of students in each class varied from 40 to 60.

Both private and government schools followed the textbooks for science developed by the Maharashtra school board, which were published in both English and Marathi. In both types of schools, for the lower primary grades (grades 1–3) an emphasis was placed on learning science through an integrated approach with a focus on such topics as: (a) our body parts, (b) our needs—food and water, (c) family and neighbourhood, (d) travel and transport, (e) the world around us. The objective of this approach was to help students understand connections between science and their everyday life. At the middle and early secondary grade levels (grades 4–7 and 8–10) students in both public and private schools learn science through a more traditional division into the various science disciplines (e.g., physics, biology, and chemistry) and often strictly follow the order of topics in the textbook.

The two participants for this study represented primary grades taught in private and government schools. The National Curriculum Framework document classifies grade bands as: 1–5 as primary, and grades 9–10 as secondary. Through purpose-

Table 2 Breakdown of teachers' education and instructional experiences

Teachers	Courses currently teaching	Educational background	Teaching experience	Other teaching/administrative duties
Public school teacher				
Sharvari	3rd grade—all subjects	12th Grade, Diploma in Education	3 years	Distributing teachers' salaries and preparing students for competitions
Private school teacher				
Bela	Science for 3rd grade only	Bachelor in Mathematics and Bachelors in Education	12 years	Helping other teachers with a special science day once a year

ful sampling, we chose a teacher from each school, representing a private and a government school (Table 2).

Data Sources and Analysis

Data sources for answering the research questions included classroom observations and a series of three interviews with teachers. Each was observed for at least four class periods (30–60 min per period). Patton (1998) describes the purpose of observation as 'describing the setting that was observed, the activities that took place in that setting, the people who participated in those activities and the meaning of what was observed from the perspective of those observed' (p. 202). Classroom observations were focused on the behaviour component of their orientations by observing their actions, activities, questioning strategies and how they used resources. The observations also helped to develop probing questions, which were used with teachers in order to understand the nature of their orientations. Classroom observations also allowed us to compare teachers' performances with thoughts about teaching science that they expressed during interviews.

Another source for answering research questions, concerning what teachers' thoughts about the goals and purposes for teaching science, were the interviews. The three teacher interviews were the main source of data for this aspect of the study with one given prior to any observations, a second after the second or fourth observations, and a third that included a card-sorting task which was developed from a pilot study in a similar teaching context in India (Nargund-Joshi, & Park Rogers, 2011). These interviews served as a second primary source of data for developing the orientation profiles.

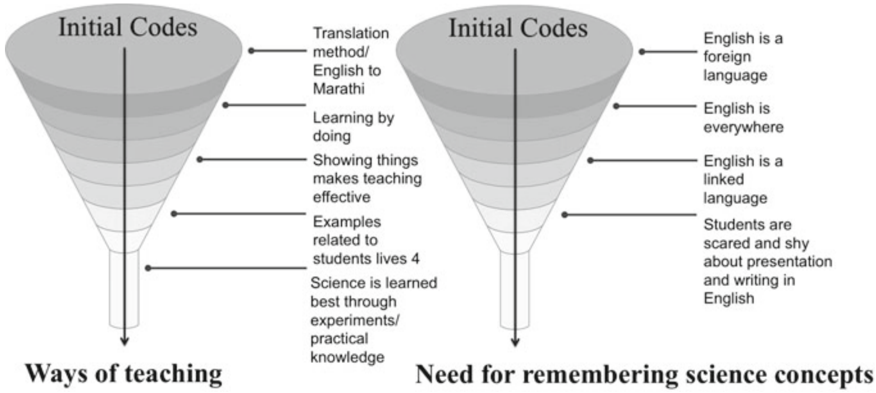

Fig. 2 Examples of initial codes emerging from data analysis

An inductive process was utilised to analyse these data during the early stages of data collection (Patton, 2002). To develop a profile of each teacher, all three interviews were analysed. The data analysis began with generating initial codes. These initial codes were grouped into related categories. This enabled similarities and differences among initial codes to be determined. Figure 2 illustrates two examples of how the initial codes were categorised.

The initial codes were put in categories and further analysed to understand relationships between them. As the coding process progressed, the main pattern in each teacher's instruction was identified. Teachers' interviews were compared with their classroom observations to generate the final orientation profiles.

Findings

To understand the nature of teachers' orientations, we developed a profile of each teacher's science teaching. A profile consists of a narrative describing a teacher's orientation towards the components of pedagogical content knowledge (PCK), including (a) the purpose of teaching science, (b) instructional strategies, (c) science curriculum, (d) assessment, and (e) student thinking. The focus of the profile description is on the teachers' conceptions and behaviour in order to detail what they know, believe, and enact in their science teaching.

Following production of each teacher's profile, we compared the teachers' orientations to pull out similarities and differences among them, thus providing a more comprehensive view of these two teachers' orientations for teaching science. This profile comparison also allows for an analysis by school type and grade band.

Nature of Sharvari's Orientations

In the class observed, Sharvari focused on teaching the topic of living and non-living organisms to students. The focus of her lesson was to make students understand differences and similarities between living and non-living organisms and also make them aware about how human beings are similar and different from other living organisms. In the last lesson of the unit, she gave the class a test based on the unit. Students take the test individually and write answers to the questions in their notebooks.

Sharvari's orientation towards the purpose of science teaching. Sharvari viewed a teacher's main purpose as preparing her students for life, for which they need to study science. She said that science is connected to everyday life and thus students should learn it. She wanted her students to remember things, not only for her class or a test, but also for their whole lives. She believed that helping children remember things for life requires showing them examples of concepts. Therefore, she felt that it is necessary to always incorporate some sort of activity or experiment, as part of the learning experience.

> To teach science we had to go through the experimental method and practical methods, by listening we remember up to 70%, but if we do practical, we remember 80 to 90% because students can study and they say 'ok! I have done this, so I know it.' But for me, to know if they really know it, they need to do something with it (Sharvari, Interview 1).

Sharvari's definition of activity and experiment included showing students a poster, taking them to the playground, or bringing things into the classroom to observe. However, students were not actually involved in collecting data in any of the observed lessons; rather they were passive observers of her demonstrations. One of the objectives of science at this stage is to encourage students to observe, record, differentiate, classify, infer, draw, illustrate and design. As a class, she set up an experiment with a plant and a rod placed in soil to teach students how living things grow and non-living things don't. She told them that they would observe the two pots for changes, but she did not ask the students to record anything about the setup or preliminary observations or even give them a question to answer in their science notebooks. In fact, throughout the six observations of Sharvari, the students were never seen using science notebooks. Likewise, she did not discuss any process skills explicitly with students.

Sharvari's orientation towards science instructional strategies. In the six observed lessons of Sharvari's science teaching, she used various teaching strategies such as charts, demonstrations, models and textbook readings as a means to support her science teaching. Also, Sharvari often taught students tricks, codes, short phrases or rhythmic patterns in order to help them remember things in the long term. She said that she used these tactics because English is a foreign language for her students and they are learning science in English so they can't possibly understand all the concepts. Sharvari believed that learning science in English would open up new opportunities for her students because, 'English is everywhere' (Sharvari, Interview 1). It is because of these language issues that Sharvari felt the need to use a lot of hand gestures and pictures when explaining concepts, and in some cases she would even translate things into the students' native language and then repeat it in English to confirm it. During one of the interviews, Sharvari explained that she often reviews vocabulary with students before reading the textbook chapter. This is because she felt that her students struggle so much with the translation of the language that she needs to first help them understand the words, and then they can learn to understand the science.

During the classroom observations, students hardly raised their hands to explain concepts when Sharvari asked questions. It is apparent that one of the barriers for understanding science concepts in Sharvari's classroom is the fact that it is taught in English. Although Sharvari explained the concepts in English and the medium of instruction is English, she spoke incorrect English herself and the notes given on the board also include incorrect English. Forcing students to learn in English also appeared to greatly restrict students' classroom interactions.

When asked how she organises her instruction Sharvari explained that she always goes from simple to complex concepts in order to connect science to the students' lives. For example, during the card sort interview (Interview 3) she gave an example of how a bicycle is built in order to teach about joints. She says that she shows (with emphasis in her voice) students a bicycle and asks them what will happen to the bicycle if one removes a piece of it? Will it still work the same way? The card that was presented to her on this topic suggested filling in an outline of the human body parts to learn about the different places for joints. However, Sharvari rejected this activity, stating '4th-grade students are young and won't understand what is meant by fill up an outline of the body.' Therefore Sharvari chose to give her alternative example of a bicycle analogy to explain joints and how they function in the body.

Throughout the card sorting interview, Sharvari rejected many of the exploratory-based activities because she felt her students were too young to perform these sorts of activities on their own. This led to Sharvari providing needed information instead of letting students explore things on their own. On a similar note, she described the textbook as an essential part of her teaching because it helped her to decide how much knowledge should be given to students and it provided students with a place to refer to, should they forget a term or concept. Although the National Curriculum Framework (NCF) states that teachers should only use textbooks as a guide or to refer to for other experiences, it is evident that Sharvari viewed the textbook and other commercial books that have questions in them as key components of her science instruction.

One of the themes that emerge from analysing Sharvari's teaching and her interviews is the level of responsibility she assumed for her students' learning. She often used phrases such as 'I must', 'I teach them first', 'I show them', 'I give them information'. She demonstrated that she deals with this level of responsibility by asking students to stand if they don't know and then repeating explanations, definitions, or examples before moving on.

Sharvari's orientation towards curriculum. From Sharvari's three interviews, the second interview focuses the most on her thoughts regarding the NCF and how she implements or plans to implement the new curriculum in her classroom. When asked if she knew of the NCF, she said 'no' but continued with the question 'our textbooks are based on this. Right? I refer to the textbooks all the time, but I am not aware of the NCF.' Some of the goals of the NCF were then shared in order to probe Sharvari's view of how well her curriculum aligns with these goals. In response to the first principle of the NCF, *connecting science with students' daily life*, she gave an example of how she tried to connect the concept of 'habitat' by describing it as a geographical location-the place in which we live. Although Sharvari was not aware of the first goal, she was able to give examples of how she incorporates its intent in her curriculum. Such examples were also observed several times in her teaching. For example, in one of the lessons, after some discussion about living versus non-living things, Sharvari asked students to draw pictures of living things familiar to them and she used these to question them and determine if they could correctly identify living examples.

With respect to the second goal of the NCF, *learning should move away from rote memorisation*, Sharvari said, 'a teacher has to do something extra than rote memorisation', but she had trouble explaining how she moves away from rote memorisation in her own teaching. Sharvari used a variety of techniques to help students remember science facts, such as putting science words to a rhyme or creating codes to remember list of facts. Therefore, in a creative way, she emphasised to her students the need to memorise the information and in this way reinforced traditional rote memorisation.

The third principle is focused *on making assessment more flexible and integrated with classroom learning*. Similar to other teachers, Sharvari was aware of this new emphasis in evaluation and described it as being more 'student-centred'. She explained that to accommodate this objective she now tries to incorporate open book tests and regular observations of students' daily work into her evaluations, but she could not explain the purpose for including these sorts of evaluative measures in her teaching.

Following the goals for science learning, the next part of the NCF states that when designing curriculum, emphasis should be placed on cognitive, content, process, historic, environmental and ethical validities (Science Position Paper, 2006, pp. 2–3). After reading about these, and with some further elaboration and clarification on my part, Sharvari noted that to achieve cognitive validity she finishes all topics listed on the syllabus for the grade level. To achieve content validity she finishes all science content by the time she has to give each unit test. With respect to process validity, Sharvari explained:

> This means how much students have understood. So during an exam, if I see that a student can do good processes, then he is good student, he has achieved this (Sharvari, Interview 2).

When probed further about this comment, Sharvari could not explain how she accomplishes process validity through her teaching but simply observed that if students can do it, then it must be a valid process. Similarly, Sharvari's understanding of historical and environmental validities was limited. For example, historic validity deals with how science changes over time, but Sharvari connected historic validity with overcoming students' superstitions, and she related environmental validity to studying environmental issues.

The third section of the NCF related to curriculum design knowledge focuses specifically on methods for teaching primary science. For example, one of the expectations for primary science is to develop students' science language through doing science. However, Sharvari approached this a little differently.

> First I must teach them the hard words and how to read the lesson and then slowly review the concepts with them. Thus language and science go hand in hand (Sharvari, Interview 2).

Sharvari demonstrated this strategy of asking students to repeat hard words after her, pronouncing them correctly but not explaining their meanings. When asked how she addresses the expectation that content should be selected and taught in meaningful ways for each age group, Sharvari stated that she taught what is in the textbook, so there is no irrelevant material presented; it is all meaningful.

A third point of emphasis for the primary grade level is knowing how to integrate science with other subjects. When asked about this in the second interview, Sharvari gave an example of evolution and how man developed over time, but she could not provide details as to what science concepts and social science concepts could be targeted through this topic. Also, no attempts by Sharvari to integrate science with other subjects were witnessed. However, when questioned about the NCF expectation of teaching science both inside and outside the classroom, she quickly shared an activity for teaching students about health and hygiene, in which they arranged a picnic on the school playground, during which they talked about the food and how to create a balanced meal of proteins, carbohydrates and vitamins. She explained that she conducted this lesson outside because students could learn the content while enjoying a picnic. Sharvari's understanding of teaching science concepts outside the classroom was to take students into an outside environment to get their attention, although such an excursion for learning concepts was not observed for this study.

The final set of grade level expectations focus on group work and free exploration which must occur in a manner that best suits the students' developmental level. Sharvari connected the notion of free exploration with having students participate in a science fair and explained how she allows her students to be creative during science fair projects and encourages them to work in groups. Sharvari's class size is small compared to the average Indian classroom, but even so she was not entirely sure about how to implement small group exploration activities in science during her regular classroom instruction.

Sharvari's orientation towards assessment. Sharvari was observed asking lot of questions to her students while teaching. During the card sort interview, she explained her purpose for this as 'Asking questions helps me to get students' attention' (Sharvari's Interview 3). This focus on asking questions to get students' attention was observed in many lessons. After explaining a concept to the students, Sharvari told students that she is now going to ask them a series of questions. Sharvari elaborated on her purpose for repeating questions.

> I will keep on asking them questions to improve their concentration. If I keep on asking them questions, they will learn to pay attention in the class. They will begin to think, if I cannot give the teacher the right answer I will be punished. Or if my friend can give the answer and not me then they will be honoured for being able to do that (Sharvari, Interview 3).

In discussion with Sharvari and through watching her teaching it was evident that she implements this purpose for questioning regularly in her practice. She does not question in order to understand students' thinking or draw out their misconceptions about a science concept or so she can modify her instruction, rather she questions simply to keep students on track and focused during her teaching. Most of the questions that Sharvari asked during classroom teaching were evaluative in nature. She framed questions to receive one-word responses, such as yes or no, right or wrong. She evaluated whether or not students could correctly answer the question in order to determine whether she needed to explain the concept again.

Sharvari's thoughts and behaviours towards summative assessment were observed while assessing students' learning at the end of the unit on living versus non-living things. In the final test after the unit, she asked many multiple choice questions, fill in the blanks, and matching questions. Examples of such questions included on this test are:

(1) Draw picture of two living things and two non-living things
(2) Write differences among living and non-living things
(3) Write names of 4 living things who have eyes on either side of head
(4) Match the pair

Bird flew high	Reproduction
Bud blossomed into flower	Movement
Cat had kitten	Growth

(1) Fill in the blanks
- Man can bring the—in front of other fingers (thumb)
- In—the eyes are in the front of head (birds)
- The—of cow, dogs and cats can turn towards sound (ears)

Each of these questions focuses on assessing students' factual knowledge based on living vs. non-living concepts only. There are no questions directed at learning about students' understanding of the nature of science or the practice of science, which the NCF states now needs to receive equal attention in the science curriculum.

Sharvari's orientation towards students' thinking. Sharvari had the opportunity to discuss her thoughts about students' thinking in all three interviews. During each interview, she often made comments such as, 'science knowledge must be fixed in their (students') minds' (Sharvari, Interview 1). To achieve this goal she first explained the concept to be learned to the students and then performed an activity to reinforce what she just explained. She said, 'The activity and concept must go hand in hand. I do an activity to clear [clarify] the concept' (Sharvari Interview 1).

In the second interview, Sharvari also mentioned that a 'child should learn by playing, using the playway method' (Sharvari, Interview 2). Sharvari explained that she learned about the 'playway' method during her teacher-training program. She described it as a method to help students engage in activities such as puppet shows, posters, models, demonstrations, and technology-based resources. During lessons, Sharvari was often witnessed using posters and demonstrations in her teaching. She also frequently used analogies, such as the bicycle example to describe the purpose of joints mentioned earlier. Sharvari's thoughts about how students learn best include activities and play and these methods are also expressed in her teaching. In each lesson observed for this study, she incorporated some sort of teaching tool such as posters, models and demonstrations. She stated that her purpose for doing so was to attract her students' attention towards science to be learned. For example, in one lesson from the living versus non-living unit, Sharvari brought a real flower as a model to teach the parts of a flower. Because of the language issues (science being taught in English rather than the students' native language), she said that she felt it is important for the students to see the parts of the flower and associate the word with that part. To reinforce the name of the parts of the flower, however, she simply repeated the names and pointed, with the students repeating the words back to her.

Summary of Sharvari's Orientation Towards Teaching Science

Figure 3 depicts Sharvari's orientation(s) toward science teaching and the contextual reasons behind them. Figure 3 indicates how Sharvari's thoughts and beliefs shape the

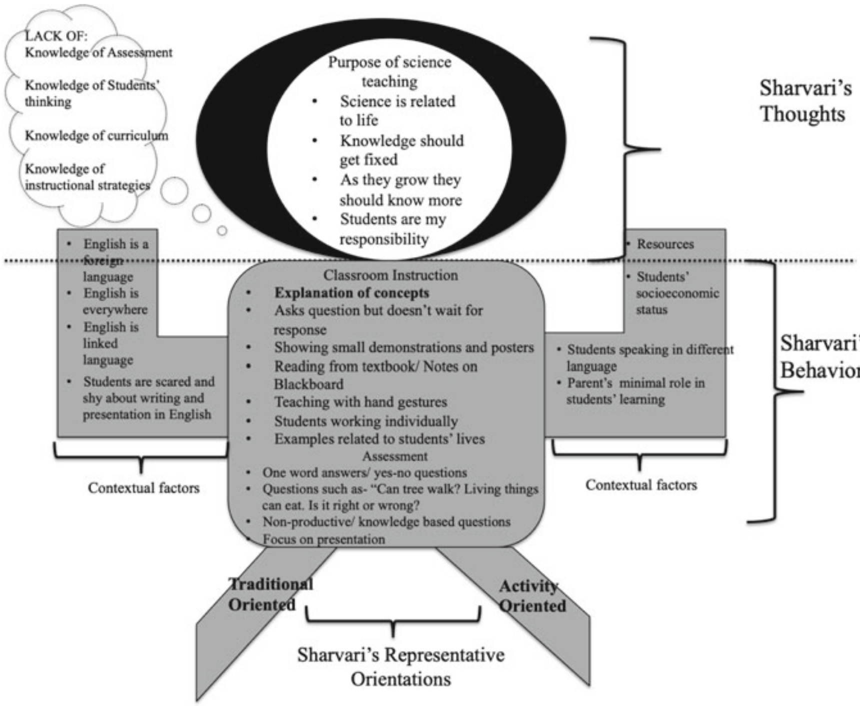

Fig. 3 Summary of Sharvari's science teaching orientation

purpose of her science teaching (Head region of the figure). However, her purpose, thoughts and her actions do not align with each other. She believes that if she explains concepts to students multiple times, they will eventually understand them. Figure 3 summarises Sharvari's classroom activities (Body region of the figure). Most of the instructional activities in a classroom focus on helping students retain information. Though Sharvari is eager to learn new things and employs multiple strategies to help her students learn the science concepts, her primary purpose is often to have them memorise the fact or word, not learn the underlying principles of the science concept. Overall, she displayed traditional and activity orientations with limited alignment to the goals of the National Curriculum Framework. These orientations guided her classroom planning and instruction (Legs of the figure). The arms of Fig. 3 indicate that the constraints that Sharvari experiences in her classroom shape her orientation.

Nature of Bela's Orientations

As we observed Bela's teaching, we noted that she was focused on the topic of living and non-living things in a 3rd grade classroom. Bela's private school is affiliated with the Maharashtra State Board, but they have adopted the more advanced textbooks from the Central Board of Secondary Education (CBSE). According to Bela, 'the state board books are for the mass (i.e. for average students), whereas CBSE textbooks are in depth and adopting them at the primary level helps set a good foundation' (Bela, Interview 1).

Bela's orientation towards the purpose of science teaching. Bela is very careful about conveying the right concepts to her students and believes that the primary level is the foundation of a good education. Later in the interview she stated,

> …whatever we give them or explain to them, we have to be particular. If we convey something wrong then they are going to do the same thing. Whatever we (teachers) say, that's final, the teacher has taught it – innocence is there, so they believe what we say (Bela, Interview 1).

Building a foundation for science learning is one of Bela's goals for science teaching, and it guided all aspects of her instruction. While teaching, Bela was observed asking many probing questions to students. Instead of fact-based questions, the majority of the questions she asked focuses on understanding why and how certain things happen. For example, while discussing the function of leaves, Bela asked her students, 'How do plants get food?' During the interview, Bela discussed her objectives.

> My objective was to help them learn difference between plants and animal and one of the characteristics of plants is they prepare their own food. So we studied that characteristic in detail. Why green plants? To understand this better we have taken examples of non-green plants such as fungus and mushrooms and are comparing to green plants. The non-green plants cannot prepare their own food because they don't have the chlorophyll they need. So the whole point was to make them understand what makes green plants green and how they use this to help them make food (Bela, Interview 2).

The second goal of Bela's teaching was to develop students' interest in science. She asserted that 'a child might have more interest in language learning, but he should not feel I don't want to do science. It is our responsibility to help the child develop and retain an interest in science, so efforts should be taken to involve students in activities or give them responsibility. Responsibility can inculcate their interest. When a child takes some efforts in finding information on their own they develop an interest' (Bela, Interview 1).

Bela's orientation towards instructional strategies. Instead of providing factual information to students, Bela was more inclined towards explaining to students why certain things happen in certain ways. During an interview we asked Bela how she approaches her science teaching, to which she replied:

> I read the textbook and make myself familiar with the concept, then I will decide instructional strategies. Students might be learning about photosynthesis in fourth grade and again in seventh grade, but in seventh grade they might be familiar with words such as stomata and photosynthesis while in fourth grade they are completely new. In the seventh grade I will explain the meaning of word photosynthesis by breaking the word into photo and synthesis, but this explanation will be difficult for fourth graders. At this stage I will concentrate on such concepts as how plants take carbon dioxide in and give oxygen out. My focus will be on explaining the interdependence of plants and animals (Bela Interview 1).

Bela is clearly aware that she should change her explanations of some science concepts according to the grade level. She also mentioned that she tries hard to avoid explaining higher-level concepts at the primary level. Instead, she may mention a word or two that are not expected at that grade level for some of the brighter students as they may go ahead and refer to them. In her teaching, Bela always asks a lot of questions, and the whole class learns concepts mainly through discussion. During our observations, we never saw Bela reading a textbook chapter to the class or asking students to read it with peers. However, during an interview Bela stated:

> I refer to the dictionary for understanding a difficult word and I underline it and give it to my students to underline. I make them write those new words three or four times. This reinforces the concept and they improve their spelling (Bela, Interview 1).

Bela frequently wrote important words on the blackboard, but she didn't ask students to copy it in their notebooks. Instead, she used them to initiate a discussion. Bela also mentioned that during her teacher training program she learned that the lesson should begin with an introduction, followed by an explanation, followed by performing an activity that illustrated the explanation. From the interviews, it is clear that Bela believed in a certain way of teaching and follows it and that her teacher-training program was the main source of information for the development of her science teaching orientation.

Bela wanted children to retain an interest in science and to achieve this goal, she often asked students to bring specimens to class. For example, while teaching about leaves, Bela asked students to bring leaf specimens into class. With these specimens, she was able to point out that leaves have different shades of green. Some leaves are yellow or yellowish green. After observing these leaves, students might question whether or not yellow leaves prepare food. By having students bringing specimens to the classroom, Bela believes they will get interested in the topics and be curious about their observations. This is one of the main principles of the NCF at the primary level, indicating Bela is fulfilling this goal.

Bela's orientation towards curriculum. When asked about the NCF, Bela denied having read or heard about this document. However, after reading the summary I prepared for interview (Appendix G), Bela could explain the principles and even associate them with her teaching. For example, she mentioned assessing group projects and activities performed by students as one of the flexible ways of assessing. She further elaborated that group projects can be assessed by asking students about their contribution to the project and how they collected data. However, Bela struggled to explain her understanding of inquiry process skills or how she chooses age-appropriate content and methods, saying, 'sorry. I won't be able to explain this' (Bela Interview 2). Though Bela provided opportunities for students to make observations, none of the observations were structured. Bela did not encourage students to draw inferences from their observations, nor did she talk about any other process skills explicitly. She agreed with the need to develop children's curiosity and creativity, but other than doing different activities, she could not think of ways in which these qualities could be developed in students. Bela's lack of knowledge about inquiry and the nature of science resulted in a greater focus on developing students' understanding of science content, but not on how scientific knowledge develops and changes or what different process skills are involved in science.

Bela's orientation towards assessment. Bela posed a lot of productive questions during her teaching and as such probed for understanding of students' thinking about the topic. When asked about her purpose for asking these different types of questions she gave the following answer:

> One of the reasons is that they (students) have misconceptions, so by asking questions we come to know what is their interpretation about plants. Asking what they mean, by saying plants prepare food, can elicit multiple answers. One of my students said, we also prepare food in the kitchen, then why don't we look like plants? So they have very different interpretations' (Bela, Interview 2).

Bela was aware of the importance of eliciting students' preconceptions before and during teaching. During one of the classroom discussions of how plants prepare food, she guided the whole discussion using multiple questions which brought students' attention to the green colour of plants, the reason for why most plants are green in colour, and how this is used to help in food preparation.

During a discussion about new assessment patterns and goals, Bela referred to the purpose of conducting continuous and comprehensive (CC) assessment.

> The new term CC has come into the educational system now. We cannot evaluate a child by asking him to write answers to questions on only one day. This cannot tell us how much the child has understood or not. So we are going to evaluate the child through activities, games, and observations. This will give more justice to the child and secondly reduce stress on the child.' (Bela Interview 1).

Bela also expressed her concern about mandatory promotion and not detaining students till eighth grade.

> If freedom is given to you, you should respect it. If there is no test then there is no fear. Sometimes it happens that when you give marks on an assignment, students perform sincerely. Unfortunately, if you are not giving marks, students might not take it seriously. Our system is mark oriented. If parents know that a certain assignment is going get graded, then it will be done well (Bela Interview 1).

Bela's understanding about the purpose of the new guidelines for appropriate assessment and the importance of knowing various assessment strategies, was evident in her teaching.

Bela's orientation towards students' thinking. During the card sorting interview, Bela mostly chose cards that involved activities and students' explanations of their thinking. During one of the card sorts, Bela responded in the following manner:

> Till 4th standard we give students question and answers as notes, because we want to develop the system. We give answers in a particular order. We want them to write a law or equation if needed first, and then an answer should be in point form, so that students will develop this habit, but in examinations we ask them application based questions (Bela, Interview 3).

Even though Bela wanted to reinforce the habit of writing answers in a particular fashion, she also wanted students to develop an understanding of questions and then write answers in their own words.

Bela sorted almost all the didactic oriented cards into the 'this does not represent my teaching' category. Bela assigned, '*You as a teacher will explain students different sensory organs by reading information from the textbook*' to the 'no' category. When she read this card, she laughed and said,

> This concept can be taught better by doing an activity. By bringing some perfume, or closing their eyes, it will be better for students to understand this concept. By reading students won't understand the importance of sensory organs and by this way [experiencing sensory stimuli] they will retain it better (Bela, Interview 3).

This preference is also observed in her teaching. During lessons, she explicitly discussed students misconception related to respiration and had them think about, or even do, their own breathing in and out to demonstrate this idea.

For some of the cards, such as those referring to process and inquiry, Bela struggled with putting them into categories because, although she liked certain activities and she could see herself doing them, she felt time constraints might not allow her to do so. Instead, Bela pulled examples from her teaching to explain how she might use the same idea in the scenario but modify it a bit to address the time constraints in her class. As for cards explicitly discussing process skill development, she felt these sorts of experiences would be more appropriate for science fair projects. Therefore, it seems that Bela did struggle with understanding how to incorporate process skills for her students into her daily science instruction.

Summary of Bela's Orientation Towards Teaching Science

Figure 4 depicts Bela's orientation(s) toward science teaching and the contextual reasons behind them. Figure 4 indicates how Bela's thoughts and beliefs shape the purpose of her science teaching (Head region of the figure). Overall, Bela is more student-centred in her teaching than Sharvari, and seems to have a less authoritarian teaching style, even though she admits she is not consciously following the reform principles. She also seems better informed about science concepts than her public school counterpart, Sharvari. Figure 4 summarises Bela's classroom activities (Body region of the figure). Bela was aware of different ways to conduct formative assessment and elicit students' misconceptions explicitly. Overall her orientation towards student thinking and teaching science is that of conceptual change with some characteristics also related to an inquiry orientation. These orientations guided her classroom planning and instruction (Legs of the figure). The arms of Fig. 4 indicate the supports that lead Bela to display a reform minded science teaching orientation.

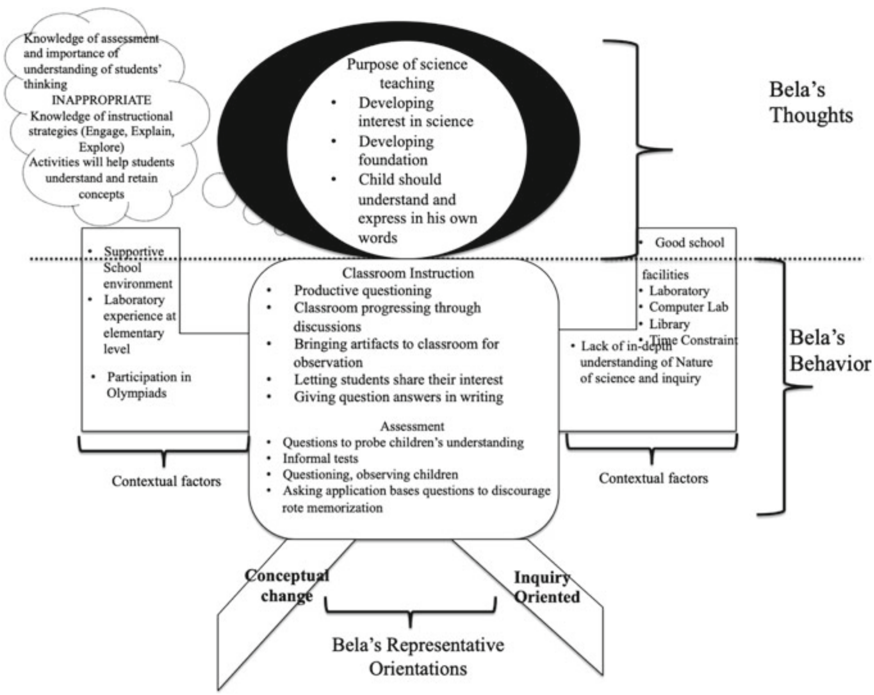

Fig. 4 Summary of Bela's science teaching orientations

Conclusions

The purpose of this study was to understand two primary Indian teachers' orientations towards teaching science and how these orientations may vary by school type. To accomplish this we created profiles of the teachers' orientations based on both conversations with the teachers and observations of their practice. These profiles allowed us to cross compare the teachers' orientations and gave us insights about the contextual factors that may be influencing teachers' orientations according to school type.

Sharvari, in a public school setting, displayed traditional orientations towards science teaching. She used a lot of teaching aids such as charts, models, and puppets in her teaching to engage students, and she believed that if she did not use such tools, students would not be engaged. She also used these tools, to explain things better to students because they had to learn science in English rather than their native language, and the visual aids helped to reinforce the English vocabulary. Sharvari explained that she was not aware of the principles or science specific validities outlined in the National Curriculum Framework, and in one of her interviews she shared that she had not received any professional development that explained the framework. Sharvari was aware, however, of the new assessment expectations, as her school required her to make daily observations of her students' work in class as part of their new evaluation strategies. However, much of her questioning focused on asking students about simple factual content (testing if they are right or wrong) rather than as a means of formative assessment to understand how students' were thinking and what struggles they might be having with a science concept. In addition, Sharvari believed that if she explained a concept to students more than once they would understand it better and be able to explain it better for a test. She also thought that concepts needed to be explained before performing an activity that explored or contextualised the concept. Therefore, Sharvari was identified as having a traditional orientation because it was evident she did not have knowledge of how students' learn science conceptually by letting them first explore the concept and then helping them to develop an explanation from their experience.

In summation, Sharvari's traditional science teaching orientation displayed characteristics of didactic teaching, a focus on memorisation, and performing activities or class demonstrations with little connection to using these experiences to help students explain concepts. She also displayed an activity orientation toward science teaching. That is, the teacher performed activities and demonstrations in the classroom, but the focus was not on conceptual change. This conclusion suggests the need for professional development programs targeting the goals of the National Curriculum Framework and different areas of Pedagogical Content Knowledge which may equip teachers better for classroom instruction.

Bela displayed characteristics of conceptual change and inquiry-based orientations towards science teaching. Bela believed that a student's experience in the elementary years is a foundation for that student's lifelong learning and therefore, she was very careful with what she taught and how she taught in the classroom. She focused on explaining concepts to students so that they would learn the meanings of the scientific words before memorising the word itself. She also explained how she wanted her students to understand the interconnectedness of scientific concepts. Still, Bela followed a sequence in her teaching in which concepts were first explained and then explored. However, the difference between Sharvari's teaching and Bela's teaching is that Bela consistently had the students involved in investigations in order to further developing an understanding of the concept. Bela wanted her students to be interested in science and believed the best method for achieving this goal was to have students experimenting with concepts, studying specimens. Therefore, Bela took her students to the science laboratory regularly, where they had the chance to make observations, analyse data, and draw conclusions based on evidence gathered.

Bela, like Sharvari, was unaware of the principles and science validities stated in the National Curriculum Framework, although both were interested in learning more. Bela's orientations were identified as conceptual and inquiry-based in nature, which aligns well with many of the principles of the National Curriculum Framework. During observation it was evident that Bela was connecting many of the science-specific validities in her teaching, however, she was less confident in her explanations of how she saw herself accomplishing these in her teaching. This suggests the need for teachers such as Bela and Sharvari to attend professional development that (a) clearly outlines the goals of reform—generally and content specific, (b) targets science specific pedagogical methods for transforming both content knowledge and science practices into forms accessible to students, and (c) includes explicit and reflective discussion of the Nature of Science to address the historical, environmental and ethical validities of science.

The nature of science teaching orientations is very complex because of the intertwined relationship between the teachers' thoughts, beliefs and classroom actions. Because of the complex nature of orientations, it is difficult to identify a single orientation for a teacher. Science education literature also indicates that teachers hold more than one orientation towards science teaching and learning and our study supports this claim (Friedrichsen & Dana, 2003; Schwartz & Gwekwerere, 2007). Although teachers might hold multiple orientations at once, based on our findings they appear to strongly display one science teaching orientation at a time. The in-depth analysis of Sharvari's and Bela's orientations allows us to understand shades in their orientations and how these orientations are shaped because of external factors. Figure 5

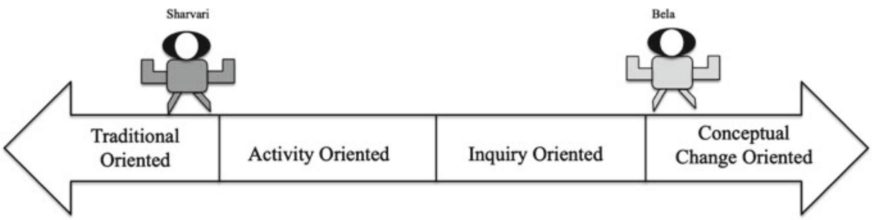

Fig. 5 Science teaching orientations of primary teachers on a continuum

depicts how Sharvari's and Bela's orientations fell on the opposite ends of the orientation continuum because of contextual factors and answers research question 2. Both these teachers held clear goals of supporting their students' learning, however lack of resources, professional development and opportunities to reflect lead them to display contrasting orientations. Teachers from different school contexts and different grade band levels displayed a range of orientations from traditional to constructivist or inquiry based. For example, the context of the public primary is very different from that of the private school. Sharvari's school has students mainly from low socioeconomic backgrounds, most of whose parents cannot read and write in their native language let alone in English; therefore, students receive very little help with their studies at home. However, each teacher notes that there are many external factors hindering her from teaching in ways they truly believe help students to learn best. Sharvari hopes for more participation from parents because they believe that the lack of support at home affects their abilities to teach effectively. In addition, teachers need better facilities to work in. Sharvari's school lacked a library, computers and a science laboratory or equipment affecting her abilities to teach science effectively. Another factor affecting Sharvari's orientations is the requirement to teach in English. She had her own schooling in her native language and so she struggled with teaching in English. Her students also had minimal exposure to English outside of school, which affected their abilities to learn in English. When observing her teaching, we saw Sharvari making mistakes in both her writing and speaking in English. It was obvious that explaining science concepts in English was a struggle for her, and it restricted her ability to offer examples in their explanations. This language barrier put a restriction on overall classroom interaction and made Sharvari resort to a lot of hand gestures and activities to explain simple terms. In contrast to Sharvari's public school experiences, Bela believes her orientations are well supported by her school context. She felt her private school setting nourished her ideas about how to best teach science and provided many of the resources they deem necessary for implementing a more constructivist model of teaching. For example, these teachers have regularly scheduled meetings as a science team in which they develop tentative plans for the year and detailed plans for each week. This opportunity for collaboration helped these teachers to set long term goals and short term objectives, as well as decide what materials or resources are required. Bela's school was also unique in the sense that it has a laboratory setting for the primary and middle school students to use, which helped with incorporating small inquiry-based activities. Bela also stated that they were regularly offered inservice programs, some of which introduced them to ideas of formative and summative assessment, project-based science activities, and various other ways of assessing students' thinking. Their school also encouraged students to participate in science and math Olympiads and other activities related to science. Finally, Bela had positive opinions about her school's library, laboratory facilities, and access to computers making her conceptual change/inquiry oriented.

Based on this research, we realise that teachers need support on multiple levels to make a successful transition from curriculum to classroom instruction. At the time of the study, teachers claimed to have little knowledge about the National Curriculum Framework. They had participated in one training session to learn about the goals of the framework. Teachers needed more opportunities to learn about the connections between textbooks and the framework. Policymakers should provide more accessible professional development so that teachers can understand the intricacies of the framework. Professional development programs should be designed in such a way that teachers will be given opportunities to examine the goals of the framework, curricular materials and textbooks simultaneously. This may allow teachers to understand the overlap between these documents. Also, from interviewing these teachers, it was clear they had never had the opportunity to think about their teaching. Several of them said that they were not aware that they preferred certain types of activities to others until doing the card-sorting task. Similar findings arose in a previous study we conducted with secondary science teachers (Nargund-Joshi, Park Rogers, & Akerson, 2011). Thus, it is important to add a reflective component, such as the card-sort task, to teacher training programs as well as professional development programs.

References

Anderson, C. W., & Smith, E. L. (1987). Teaching science. In J. Koehler (Ed.), *The educator's handbook: A research perspective* (pp. 84–111). New York: Longman.

Friedrichsen, P., & Dana, T. (2003). Using a card-sorting task to elicit and clarify science teaching orientations. *Journal of Science Teacher Education, 14*(4), 291–309.

Friedrichsen, P., van Driel, J. H., & Abell, S. K. (2011). Taking a closer look at science teaching orientations. *Science Education, 95,* 358–376.

Friedrichsen, P. J., Abell, S. K., Pareja, E. M., Brown, P. L., Lankford, D. M., & Volkmann, M. J. (2009). Does teaching experience matter? Examining biology teachers' prior knowledge for teaching in an alternative certification program. *Journal of Research in Science Teaching, 46,* 357–383.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95–132). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Merriam, B. M. (1998). *Qualitative research and case study applications in education* (2nd ed.). San Francisco, CA: Jossey-Bass Inc.

Merriam, B. M. (2009). *Qualitative research: A guide to design and implementation* (3rd ed.). San Francisco, CA: Jossey-Bass Inc.

Nargund-Joshi, V., & Park Rogers, M. A. (2011, January). *Modifying a card sort activity for the purpose of understanding Indian teachers' orientations for teaching science.* Paper presented at the annual meeting of Association for Science Teacher Education, Minneapolis, MN.

Nargund-Joshi, V., Park Rogers, M. A., & Akerson, V. L. (2011). Exploring india secondary teachers' orientations and practice for teaching science with respect to reform. *Journal of Research in Science Teaching, 48*(6), 624–647.

Patton, M. Q. (1998). *Qualitative research and evaluation methods* (2nd ed.). Newbury Park, CA: Sage Publications.

Patton, M. Q. (2002). *Qualitative evaluation and research methods* (3rd ed.). Thousand Oaks, CA: Sage Publications.

Schwartz, C. V., & Gwekwerere, Y. (2007). Using guiding inquiry and modeling instructional framework (EIMA) to support preservice K-8 science teaching. *Science Education, 91*, 158–186.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57,* 1–22.

Yin, R. K. (2002). *Case study research: Design and methods* (3rd ed.). Newbury Park: Sage Publications.

How Can Action Research Sustain Systematic and Structured Thinking in Participating Teachers?

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Abstract Action Research has been used worldwide as a professional development tool, especially for teachers. The fundamental premise of this work is that the Action Research Framework (Lewin in J Soc Issues 2:34–46, 1946) of Plan-Act-Observe-Reflect is aligned with systematic and structured thinking, lending itself as it does to enquiry, analysis, hypothesis and problem-solving of organisational issues. It has been legitimated as science by Susman and Evered (Sci Q 23(4):582–603, 1978), and this paper begins from the position that Action Research (AR)—in terms of the thinking that AR demands and generates—calls for a scientific approach that is contextual, and generates relevant knowledge that is located in the experiential field of the action researcher. Since critical thinking and analytical skills are at the heart of a scientific approach, such an approach is important for teachers—regardless of the subject that they teach. As teachers enable their students to develop these skills, it is important to ask—how far do they refine their own thinking, and/or examine it so as to render it more critical, analytical and probing? Do they? And if they do, how does this manifest in their own classroom practices? If they do not, how can they be empowered to do so? Through structured interviews with four teachers (three Mathematics, one Science) who had engaged in AR approximately a year prior to this research, this paper serves to explore possible outcomes of AR by posing questions such as: When teachers have conducted AR to address one or more of their day-to-day practices, does (or how can) their engagement with AR enable teachers to think systematically about and analyse critically any other issues—for a significant period thereafter? Does/how can the engagement with a sequential framework like AR empower them to sustain this structured way of thinking and acting a year or so after their AR is completed? The purpose behind asking these questions is to explore if (and how) AR can serve as a tool to make teachers veer towards greater/deeper observation of their school processes as well as their own thought processes; and enquiry, analysis and verification of their initial hypotheses in classroom processes, especially since (Science, Mathematics and even Social Science) teachers are expected to draw out these skills from their students. A set of recommendations for teacher professional development through AR is finally proposed.

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Introduction

Teachers in Indian schools who aim to develop systematic and structured thinking in their students are implicitly expected by their Principals and the parents of their students to possess this ability themselves. However, since schools seldom invest efforts in gauging the extent to which teachers are themselves honing or making use of this ability, there are even rarer instances of schools actually working towards refining this ability in teachers, in more than just a sporadic manner.

An Indian school teacher's day is usually packed with multiple tasks that include lesson planning and transaction, event planning (like school assemblies, school excursions, exhibitions, cultural programmes, sports events, debates, quizzes, etc.), assessment planning and implementation, administrative tasks (like timetabling, documenting minutes of meetings, mentoring other teachers, etc.) and attending parent-teacher meetings and staff meetings. With such varied and multi-level engagements, there is little scope for a teacher to allot a separate time slot in order to develop structured and systematic thinking. It is therefore *within this very paradigm* that such a development needs to be sought: if it is to be at all meaningful.

Action Research: A Professional Development Tool for Teachers

Teachers in a school, like the members of any organisation, need to solve organisational problems on a day-to-day basis. Apart from the all-important issue of pedagogical content knowledge that every teacher needs to equip herself with (Shulman, 1986), there are a myriad of issues spanning a wide spectrum that are repeatedly encountered by any teacher—such as managing classrooms, meeting cultural differences between students of varying backgrounds, confronting a perceived lack of synchrony between the school's stated philosophy and actual practice, transitioning from the role of a teacher to that of an administrator or mentor, and so on. In dealing with issues like these, teachers have to draw upon their existing beliefs and assumptions to devise strategies that seem best suited to the given context. While doing so, if teachers can identify their assumptions, examine their biases, verify their guesses and analyse the reasons for their success or failure, then a certain structure and systematisation *of their thinking* will emerge, the importance of which cannot be overstated.

In this work, Action Research (AR) is seen as a means of generating knowledge that is situated in the field of practice of the action researcher, and is therefore not necessarily value free. Unlike positivist science, which draws evidence 'from sense data that can be directly experienced and verified between independent observers' (Susman & Evered, 1978), AR provides a mode of enquiry that is located in the *subjective* experience of each researcher, and is therefore *not* value neutral—yet it is meaningful, in that it generates new knowledge even as the researcher solves the problem under study. The degree to which knowledge generated through positivist science is value neutral is also questionable, as explored by Susman and Evered (1978). These researchers assert that when organisations limit themselves to methods that emerge from positivist science, believing them to be value-free and relevant to organisational problems, they unwittingly employ only those methods that actually work well in systems that are *not* affected by human purposes and actions. However, since organisations are populated by human beings and are affected by their purposes and actions, AR is a far more relevant and contextual way of encountering organisational issues. In organisations, as Susman and Evered (1978) declare, 'means and ends are guided by values' and therefore, 'empirical observation and logical reconstruction of organisational activities are not sufficient' for understanding and tackling problems. AR allows the researcher to explore and arrive at the *most appropriate solution* to the problem under study, without referring to general laws or organisational practices.

Such a problem-solving process will empower a teacher who teaches *any* subject—not necessarily only a Science teacher. This paper examines if and how four teachers (one Science teacher, three Mathematics teachers) who had conducted AR on a specific issue can be supported in their efforts to use AR as a means of continuing to think scientifically about *other* day-to-day issues that a teacher normally encounters. The reasons that AR has been taken as the backdrop of this work are as follows:

- The author of this work has been engaged with facilitating AR by teachers across schools, and has found this to be a very effective way of awakening the reflective practitioner from within the teacher (Raghavan & Sood, 2015; Raghavan 2018).
- While the success of AR in triggering structured and systematic thinking in the action researcher has been remarkable, there has not yet been any significant effort to investigate the *sustained impact*, if any, on the thinking of the action researcher.
- Since AR has, in itself, proven to be effective in turning around the thinking of the action researcher with regard to the *particular AR problem* that the researcher chose to work on, it is now meaningful to explore if and how this result can be built upon further so as to keep alive the enquiry, analysis, reflection and problem-solving processes that were initiated in the teacher-researcher.
- If such processes emerge through this exploration, they can then be tried out with other teachers so as to examine their efficacy in refining the systematic and structured thinking of teachers.
- If teachers can be empowered to systematically examine their day-to-day experiences, this could bring them out of the commonly experienced maze of problems that appear to defy solution, both in their number and complexity. This, in turn, could allow them to anchor more convincingly the development of enquiry, analysis and hypothesising in their students.

Background

AR has been used worldwide as a reflective process that allows enquiry into one's daily practice. Instead of being theoretical, AR draws the researcher and practitioner into a systematic examination of day-to-day practice so as to address concerns unique to the researcher and thus bring about change. The distinctive element in AR is *praxis:* practical diagnosis complemented with the reflective element (Elliott, 1991; Schon, 1983). It is this element that demands the iterative reflection-in-action that has been described so eloquently by Schon (1983). In so doing, AR naturally empowers its participants even as it demands collaboration and reflection. AR has been employed worldwide as a professional development tool for teachers and school administrators (Corey, 1953; Elliott, 1991; Glanz, 1999; Nunan, 1997) and it presents exactly such a possibility, providing as it does a systematic framework for examining and working one's way through *every day issues that pose as problems*. For a comprehensive literature review of AR, the reader is referred to Raghavan and Sood (2015) which also carries an overview of the use of AR across different domains.

Vocabulary

Since there are currently multiple usages of several words that will be used throughout this paper, it is meaningful to explain their usage here, right at the outset. The term *action research* is used in this paper, as it was defined by Lewin (1946), where the act generates critical knowledge even as it brings about a change. According to Rapoport (1970), AR has five phases: diagnosing, action planning, action taking, evaluating, and specifying learning.

Systematic and structured thinking, as used in this paper, refers to enquiring, analysing, planning and acting to solve identified problems that *arise out of the researcher's experience*. On occasion, this is also referred to in this paper as *scientific thinking*—especially if it means the identification of a bias, assumption or conclusion that has been drawn without back up of authentic data. Since this work is placed in the context of the teacher, the 'laboratory' is the teacher's groundswell of experience, with the 'experiments' being the teacher's strategies to address the issues that arise from this experience, after having examined and analysed them so as to diagnose likely cures.

The stark contrast, therefore, between positivist science and AR is the inevitable interdependence between researcher and system that exists in the latter and is absent in the former. The important processes that are under scrutiny here are enquiry, analysis, planning, implementation of strategies, evaluation of (and reflection on) their impact.

Impetus

This author began adopting AR as a tool for facilitating teacher development after several years of employing workshops as the main mode of engagement with teachers. While the latter proved to be somewhat impactful in the short term, this author was left highly dissatisfied by the lack of sustained impact on the teachers who participated in these workshops. Among the multiple reasons for this lacuna, the most significant was the fact that the themes of the workshops were seldom aligned with each participant's unique needs. This resulted in a one-cap-fits-all approach, something that the teachers themselves were discouraged from adopting in their own engagement with students! It was, therefore, inevitable that this author anchored a research study in 2014 with several teachers of a semi-urban school in North India, wherein AR was explored as a tool for engendering reflective practice. The success of this project resulted in the book *The Reflective Teacher* (Raghavan & Sood, 2015) and the strengthened conviction in this author of the power of AR. Presently, this is the main mode of engagement employed by this author, with teachers across schools in India.

Methodology

The AR conducted by these teachers was facilitated by this author over a period of 2 years and their work is currently under publication as a book (Raghavan, in press). In order to reduce subjectivity, the exploration of its sustained effect, if any, after the completion of research was not carried out by the same person. Instead, another teacher educator and researcher—who had *not* played any role in facilitating the AR of these teachers, and had, in fact, not engaged with them at all until this exploration—undertook to interview them and audio record the interviews. The author was acutely aware of the possibility of steering the discussions towards her desired conclusion, so this division of tasks helped greatly in reducing unconscious bias in the tone and structure of the interviews.

The interviews comprised the following questions:

1. How much time has elapsed since you completed your AR?
2. During this time, have you noticed any potential AR problems that emerge from your daily life? Professional or personal?
3. If you have, can you spell them out now? If you haven't, go to Questions 6 to 7.
4. Can you analyse one or two of these problems now? How would you identify strategies for these?
5. Did you try and implement any strategies to address any of these issues? If yes, describe what you did. If not, describe the impediments to doing so.
6. Can you recall instances when the major learnings from your own AR popped up in your mind, after you completed it? If yes, describe each of these triggers in detail. (What happened to make you reflect on your learning from AR, how it affected your thinking about the situation that triggered it, etc.)

7. If you can't recall any such instance, how (if at all) would you say that AR has affected your thinking?

In a sense, this was the process that Schon (1983) terms 'reflection on reflection-in-action'. Transcription of the recorded interviews followed by an analysis of the findings was carried out by the author.

School Setting

The teachers in this study worked in two alternative schools in Bangalore, Karnataka. In order to interpret the term 'alternative' schools in India (Vittachi & Raghavan, 2008), it is important to first understand what these schools are *an alternative to*, by comparison with mainstream schools in India. Most mainstream schools in India are geared towards ensuring high student achievement in the final examinations and securing high positions so as to allow their admission into the best colleges. Therefore, teachers in these schools are hard pressed to 'cover the syllabus' and maximise their students' performance in examinations. By contrast, the focus in alternative schools is less on exam scores and more on learner-centric pedagogies which empower a child to learn at his/her own pace.

Kanchana Suryakumar worked in Poorna Learning Centre (www.poorna.in) while the other three teachers worked in Prakriya Green Wisdom School (http://www.prakriyaschool.com/site/). Both schools are atypical of mainstream schools in India, in that they do not encourage competition or comparison, do not have school uniforms (which mainstream schools in India do), maintain small class sizes (less than thirty students to a class) and encourage their students as well as teachers to reflect on teaching-learning processes through various means such as collaborative work, enquiry-based explorations like AR and Reflective Writing. It was therefore against this background that the present investigation of the lasting effects, if any, of AR on the thinking of the teacher-researchers was carried out.

Sample Selection

The sample of teachers was small and selected purely on the basis of time elapsed since completion of AR. Four teachers who had conducted action research (with facilitation by the author) were approached for this study. They had all completed their AR about six months to a year before they were approached. Given the small sample, none of the findings generated herein can be generalised or statistically validated. However, they can provide leads on possible ways of keeping alive the systematic and structured thinking that AR triggered in teachers, post-AR.

Action Research was not familiar as a professional development tool to any of these teachers prior to their embarking on it. This facilitator, therefore, had to first initiate them into AR, and then facilitate their individual research, as below:

- A one-day workshop was conducted for all the teachers of each of these two schools, which explained to them the steps involved in AR, showcased a few case studies and afforded an opportunity to participating teachers to brainstorm on 'action-researchable' issues in their own schools.
- Following the above, certain teachers of each of these two schools opted to undertake AR, and were supported to do so by their school principals. This support manifested in these teacher-researchers being assigned certain time slots during the teacher's workday to meet the facilitator, read research papers, think through their AR and eventually, to document it.
- The facilitator met with each Action Researcher for an hour every month, and remained in electronic correspondence with them through the periods between meetings.
- The process adopted for facilitating AR by this author has been described in detail elsewhere (Raghavan & Sood, 2015) and so it is not being detailed here.
- On an average, each of these teacher-researchers completed their AR in a period of seven months (Raghavan, 2018), with the collaborative AR taking three years.

All of the above was done prior to the work that is described in this paper.

While the action research of all four teachers is currently under publication (Raghavan, in press), a summary of their AR is presented here for the purpose of completeness.

Radha Ravi completed her AR eighteen months prior to this study. She had been a corporate trainer prior to joining a school in Bangalore as a Mathematics teacher. In her third year at this school, she was asked to don the role of mentor to some teachers. Faced with this daunting task, therefore, she opted to conduct AR on *finding and meeting challenges in her new role of mentor to other teachers*.

Geetha Nadarajan was in her sixth year of teaching at the time of writing this paper, and she completed her AR twelve months prior to this study. Increasingly, she had begun to feel discontented while teaching Science in a school, as she found that the human qualities of each child were not being nurtured in their attempt to excel in the subject. In Geetha's worldview, *this is not science*. Unless it is a humane effort, the learning of the subject is incomplete, she asserted. So she conducted AR on *bringing together the head and heart in the teaching and learning of Science by fifth, sixth and seventh graders*.

Sudha Ravi had been a teacher for over two decades at the time of this study, and she completed her AR seven months prior to this study. Since Sudha was a Mathematics teacher as well as an administrator (Headmistress), her role empowered her to plan and implement several far-reaching interventions during the AR. Noting, with concern, the compromise of rigour in order to make learning fun, she conducted her AR on *bringing a balance between rigour and flow in the Primary Section of the school*.

Kanchana Suryakumar had been a Mathematics teacher in a school for six years at the time of writing this paper, and she had completed her AR six months prior to this study. Being a Mathematics teacher, she noticed the struggle that students faced while meeting the demands of a uniform curriculum for each age. She carried out collaborative AR (along with two other teachers) on *allowing students to learn Mathematics at their own pace through a mixed age group (MAG) setting, rather than a single age class*.

Data Analysis

Since this exploration consisted largely of probing teachers' thinking and practice through structured interviews, the data analysis did not require more than a compilation and comparison of responses. While scrutinising each teacher's answer to the specific question that was asked, similarities and differences across this sample were also gleaned. Each response was viewed against the backdrop of the time period that had elapsed since that teacher completed her AR. Emergent findings like what could perhaps have been done in order to sustain the momentum generated by AR were noted, along with the results that the questions directly yielded. Sometimes, the respondents talked about issues that the interviewer did not overtly raise as questions. For instance, the importance of documentation was articulated by some of the teachers, even though it was not pointedly asked as a question. These responses were also recorded exactly as they were received. While subjectivity and bias were minimised (by having another person ask the questions, as already mentioned), no claim to complete objectivity is being made here. Given the likelihood of human failing in recall, subjectivity in perception and therefore, a certain tentativeness in conclusions that were articulated, the results nevertheless did yield some valuable learnings for sustaining thinking and reflection in the teacher-researcher.

Results

Radha Ravi has been using the main learning from her own AR as she continues to play the role of mentor to different teachers. Her AR proved to be of great value in that she started by donning the new role with a high level of diffidence and tentativeness, and by the end of her AR cycle, expressed satisfaction at her increased self-confidence and comfort in that role. However, she admitted candidly that her conversation with the interviewer made her realise that she had completely neglected using AR as a tool in her daily life, save vis-a-vis mentorship—her specific AR problem. She realised through this conversation that she could have benefitted greatly if she had tried applying the AR framework to different issues—even without a facilitator—and confessed that while she has retained her ability to identify a problem, she has not gone beyond that. She now sees the value in doing that, instead of regarding her AR as over and done with, now that she is a successful mentor.

Geetha Nadarajan acknowledged that her science teaching has become more holistic after her AR as she works to ‘bring together head and heart’. Although she had initially intended to focus on the students in her class, to see if they were balancing head and heart during learning, the AR drew her attention to her own situation and she realised that she was herself prone to exhibiting more heart than head, and this biased her observations of students. She continues to catch herself even in personal relationships, where she admits that she needs to balance her head and heart. She recalls distinctly how—when she was called upon to furnish quantitative data about children who were ‘not exhibiting enough heart’—she actually found only one-third of the class was so! All the while, she had imagined the number to be far higher. This is something that she remembers with great force. It has made her revisit statements where she freely used the word ‘everyone’… she reminds herself that sweeping generalisations are not accurate. She also recalls the effectiveness of story-telling in science classes, and how she discovered that she, too, was good at telling stories. She is still trying to strike a balance between her own head and heart, and she questions herself and consciously brings herself back to the middle path every now and then. She notes with pleasure that she is no longer ‘stuck’ as she used to be. Her earlier block towards documentation has now vanished. She now finds it easy to document and has realized the importance of documenting cultural aspects as well as classroom processes. She thinks her documentation habit will stay with her as it is giving her a lot of clarity. AR has enriched her by making her recently assigned role of mentor very meaningful; she declares that she is able to play the role authentically. She also finds that she is able to convey with conviction to other teachers the way that she began looking at science, post AR. She has been able to identify her time management skills as a very potent area for her to do AR, but this was a problem that had been suggested by her facilitator. She could see that a possible strategy for this AR would be for her to lay out a schedule and stick to it. She has slowly started making such efforts by making schedules.

Sudha Ravi regards the AR modality as an approach that helps her look into factors connected to day-to-day concerns, something that she liked, especially the emphasis on *hard data*, not just based on feelings and whims. The step-by-step approach of AR through facilitation enabled her to join certain dots, which had been missing, on occasion, in the past. She used this approach with children even after completing her own AR. Her paper was on balancing rigour and flow, and that has remained very close to her focus thereafter. It has percolated into her personal life also, where she sees such a balance now. She finds that many problems that come up are potential AR problems. An example is the recent Government ruling to make the use of the language, Kannada, mandatory from Grade I. This ruling throws up approaches that are in contrast to the school’s approach to Language learning, and Sudha sees this as a potential action-researchable issue. At the time of writing this paper, it is currently being studied by using AR. Not all teachers have been introduced to AR, but those who have done AR are able to facilitate the others to use this framework for this issue. Using the modality of AR, the group is not hastily arriving at decisions, but is looking for hard data first. AR has taught her not to *assume* things, but to substantiate her assumptions with hard data, and she found it interesting how the solutions that AR led to were not in any way extreme or unusual. They were simple solutions which were actually all around her, but were being missed, for some reason or the other, and AR helped her to get in touch with them. AR has sensitised her and her colleagues to the native wisdom of the RtE[1] children and as a result of the AR study, she and her colleagues include this perspective in their transactions. She will continue to value rigour and flow both in others as well as in herself, and she will demand this balance from her context. She feels that AR helps her in seeing the whole picture—looking at multiple factors that impact a situation—and also in gathering hard data to substantiate a conclusion, instead of relying on feelings and opinions alone.

The facilitation of **Kanchana Suryakumar's** three-year-long AR (by the author of this paper) came to a close six months prior to carrying out this study. Coming from a corporate space, she found too many parameters to deal with in education and could not clearly see what to do and how to go about it, even though she sees herself as a structured person by nature. However, the AR framework gave her clarity, as it helped her realise that something like this can be done on a small scale to bring in tangible results which she can show as evidence for what has worked/not worked. Collaborative AR gave a platform for her and her peers to discuss and work together in a structured manner, which they all benefitted from enormously. What seemed like a huge and insurmountable problem became something that could be tackled as the AR framework was steadfastly adopted. Through the first year, facilitation helped in pruning the 'action' from the 'research', and this helped the efforts pan out in the second year so as to render the research meaningful. Now ending the third year of AR, she has been motivated by this to begin working on another research project: error analysis, based on data that she has already collected over this three-year period. She has also been advocating the AR framework to her peers, whenever they come up with issues. Doing it formally with a facilitator makes a huge difference, she acknowledges. She is willing to don the role of facilitator for her peers. She cannot recall any enhanced ability to identify a problem as a consequence of doing AR. She regards AR as a framework that helps her work through a problem, rather than help her identify it. The documentation process helped greatly in reflection. For the first one and a half years, documentation was informal, in the form of minutes or short notes. When she and her co-researchers began formal documentation and the numbers actually reflected their gut feeling, it was an 'aha' moment for them. It even changed some of their strategies for the next year. She finds AR to be *one kind* of scientific framework. It could also be adopted in a non-scientific domain, for example, the personal domain in dealing with such things as anger management. The AR framework can be used there, too, she declares. She liked summarising her work

[1]Right to Education Act (RtE) was passed in 2010 and necessitates that 25% of admissions to schools draw from the underprivileged section of society. Urban schools face the challenge of integrating children from widely disparate backgrounds as a consequence, and Sudha Ravi works in an alternative school that is actively addressing this issue.

in the form of a paper, and found it very exciting. She would like to keep such a goal on an annual basis so that she can continue to share her work with her colleagues on a regular basis. She is confident that something will keep coming up where she can use her structured, scientific manner of documenting.

Discussion

All four teachers continued to use the main learning from their specific AR problem, for instance, Radha Ravi continued to be alert to the challenges that she faced during mentoring, Geetha Nadarajan was consistently alert to balancing head and heart in teaching and learning Science, Sudha Ravi was acutely aware of balancing rigour and flow and Kanchana was conscious of the modality and effectiveness of mixed age groups in teaching and learning Mathematics.

However, since the intent of this study was to explore if their learning from AR went *beyond their specific AR issues*, so as to lend greater structure and systematisation to their thinking, the above findings are now examined further in that light. It is evident that a range of conclusions can be drawn, as the power of the AR framework emerged for one teacher, only, *during* this exploration, while it inspired some others to adopt it in their work long after they completed their specific AR.

For ease of reading, recommendations are stated *after* the conclusions from which they flow. The conclusions are listed as follows:

1. All four teachers acknowledged the power of the AR framework to help them work their way through day-to-day issues in a systematic and structured manner.
2. Reflection on the nature of science and science pedagogy was triggered in one teacher–researcher, as a consequence of her AR on bringing together the head and heart in science teaching and learning. For another teacher, the need to examine multiple factors that affect a single event emerged with great force, thus making her realise the complex nature of seemingly simple issues. Yet another saw in the AR framework a powerful way of working her way through issues in the personal as well as professional domain.
3. One teacher-researcher was struck by the simplicity of solutions that she adopted and implemented during her AR and noted that they had, in fact, been all around her, but had somehow escaped her notice until she began doing AR.
4. As long as *a facilitator was engaging with these four teacher-researchers*, they were all feeling empowered to use the systematic framework to think systematically. Having completed the AR, however, only two of the four teachers entertained the possibility of continuing to use the framework to their advantage.
5. The skill of identifying a problem—the first step of AR—appears to have stayed with all four of these teacher-researchers, although one of them stated that it was *not* a new skill for her. This is a valuable skill as, most often, teachers are plagued with numerous problems which they find hard to pin down and articulate

in a clear and researchable manner. This often precludes the possibility of their emerging free of the tangle.

6. Two of the teachers adopted this framework to solve new problems that they later identified. Significantly, *these were the two teachers who had completed their AR most recently*, out of the four in this sample. The ability to diagnose and analyse a problem in depth has been used by two of the teachers for Teaching Kannada and Error Analysis.
7. The need to support one's claims with hard data came through forcefully for at least two of these four teacher–researchers. The awareness of avoiding making sweeping generalisations without sufficient data impacted these two teachers' day-to-day functioning thereafter. The significance of this cannot be overstated as a teacher's interventions are frequently steered by certain assumptions, often untested for validity. This is also valuable, especially if teachers are to demand the same rigour from their students in Science classes.
8. Documentation of their AR-enabled these teacher-researchers to step back and look at their work, even as it opened up some new areas for a couple of them. When a teacher begins to see value in documentation, a doorway to objectively examine her day-to-day work opens which, in turn, allows critical analysis and, eventually, problem-solving.
9. Another interesting consequence of AR was the opening up of new roles for teachers. One of these teachers began facilitating AR by her peers, while observing that this framework prevented them from slipping into a habitual tendency of spontaneously arriving at unsubstantiated conclusions. Another felt equipped to don the role of facilitator of AR by her peers, which may well happen in the future.

These four cases illustrate the possibilities that lie embedded in AR: for igniting, nurturing and sustaining a systematic and structured way of thinking in teacher–researchers. It also shows the critical role played by a facilitator. Teacher development necessitates the periodic engagement of an in-house mentor with teachers, who are experienced and can initiate reflective thinking in teacher–researchers. Certain processes need to be put in place if teacher education is to be meaningful and contextual, processes that enable teachers to identify and then question assumptions, support their own conclusions with hard data, demand such data from their peers for their conclusions, and articulate day-to-day issues as researchable problems.

The importance of AR as a professional development tool was acknowledged and experienced in tangible ways by each of these teachers. However, the lasting effects of this tool depend significantly on the School Heads supporting and sustaining the process. There is immense value in Heads of Schools or Senior Teachers engaging periodically with teacher-researchers to explore the impact of the AR on their day-to-day functioning, long after they complete their AR. This can keep open the minds of the teacher-researchers to the possibility of using this framework *without the presence of an external facilitator* or even inspire them to don the role of facilitator for their peers to conduct AR. Tapping into each other's expertise, a rare practice amongst teachers in most

Indian schools will be only one likely consequence of such role change. Just as one teacher–researcher was struck by how she had missed noticing the availability of solutions to her AR problem, such interactions between teachers may well make them note skills in their own peers that had thus far escaped their attention. The shift in dynamics between colleagues that is likely to ensue, as a result of such role changes, can do far more to initiate *organic* teacher development than the customary teacher-development workshops that schools typically organise annually–mostly conducted by external resource persons. Further, by encouraging regular, reflective documentation of their pedagogy as well as classroom processes, in-house mentors can aid teacher-researchers in using AR as a tool for opening up avenues of critical analysis and self-reflection. In-house mentors for documentation can bring about dramatic changes in the way teachers perceive themselves, their pedagogy, as well as the subjects that they teach.

School principals can build on the above to keep alive the spirit of enquiry, critical analysis and problem-solving in their teachers, without which they cannot truly envision the same skills being honed in their students. When scientific thinking in teachers extends beyond a laboratory or science class, and they even begin to examine their own thought processes, there is far greater chance of teachers nurturing the same in their students.

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References

Corey, S. (1953). *Action research to improve school practice*. New York: Teachers College, Columbia University.

Elliott, J. (1991). *Action research for educational change*. Bristol, PA: Open University Press.

Glanz, J. (1999). A primer on action research for the school administrator. *The Clearing House, 72*(5), 301–304.

Lewin, K. (1946). Action research and minority problems. *Journal of Social Issues, 2,* 34–46.

Nunan, D. (1997). Developing standards for teacher-research in TESOL. *TESOL Quarterly, 31*(2), 365–367.

Raghavan, N., & Sood, V. (2015). *The reflective teacher: Case studies of action research*. Hyderabad: Orient Blackswan.

Raghavan, N. (Ed.) (2018). *Teachers as researchers: Research papers and narratives by teachers of Prakriya Green Wisdom School* (under publication by Bhoomi Publications).

Rapoport, R. N. (1970). Three dilemmas of action research. *Human Relations, 23,* 499–513.

Schon, D. A. (1983). *The reflective practitioner: How professionals think in action*. New York: Basic Books.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Susman, G. I., & Evered, R. D. (1978). An assessment of the scientific merits of action research administrative. *Science Quarterly, 23*(4), 582–603.

Vittachi, S., & Raghavan, N. (2008). *Alternative schooling in India*. New Delhi, India: Sage Publications.

Inclusivity and Access in Science Education

Addressing Diversity in Indian Science Classrooms

Rekha Koul

Abstract Given the diverse socio-cultural nature of the student population of Indian classrooms, it is imperative that science teachers be prepared to critically examine, reflect on and respond to practices for learners with diverse needs and from diverse backgrounds. Language development, students' contextual understanding, world-views, quantitative and visual-spatial reasoning skills and social skills, all contribute to preparing students to become scientific literate citizens? Professional development of science teachers is a crucial step in addressing these issues. This paper reports the findings of two research projects, where three-day professional development workshops were conducted for Indian science teachers in two different cities namely Mumbai and Gwalior, to enrich their teaching practices in diverse classrooms. Indian science teachers were introduced to and then engaged in inquiry-based teaching methods based on the Australian Academy of Science, *Science by Doing* materials. The professional development workshops provided opportunities for teachers to ask questions and work collaboratively with their peers to generate novel solutions to the questions raised using their science content knowledge. Most teachers enjoyed the workshops and found the content and pedagogies used for delivering workshop useful. However, they expressed a need for activities aligned with commonly used textbooks and for teaching large classes with few resources.

Introduction

India constitutes 17.75% of the world's total population with a median age of 27 years, adding roughly 15 million people each year and 30% of its population is under 15 years of age (Worldometers, 2019). The youth of India are likely to become a major international workforce and it is imperative for educators and policymakers to make sure that these young people have a sound understanding of science and technology which is deemed to be having 75% of jobs worldwide (Department of Jobs and Small Business, 2017).

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Unfortunately, Indian secondary school students have performed poorly in science international tests. India was in the 72nd place out of 73 participating countries in the last *Programme for International Student Assessment* (PISA) they participated, organised by Organisation for Economic Co-operation and Development (OECD, 2012) and thereafter India has not participated in International tests. The assessment focusses on reading, mathematics and scientific literacy of 15 years old students. With this background in mind, the author undertook few teacher professional workshops to better equip science teachers with alternative teaching strategies which can help Indian students to achieve a better conceptual understanding of scientific processes. This involved the professional development of Indian science teachers with a focus on student socio-cultural diversity and science inquiry. The primary resource used was the 'Science by Doing' professional learning resource developed in 2010 by the Australian Academy of Science (Science By Doing, 2010) because of author's familiarity with this resource and it's proven efficacy with student diversity in the science classrooms.

The characteristics of Australian classrooms and Indian classrooms may seem different; however, an important similarity is the diverse socio-cultural nature of the student population. While these aspects are found in varying degrees across the students in classrooms in any part of the world, addressing them poses a challenge in the face of socio-cultural diversity, e.g., diversity in ethnicity, religion, region, habitat, language and gender (Sobel, Gutierrez, Zion, & Blanchett, 2011).

Preparing teachers to teach students from diverse backgrounds and with diverse academic needs is one of the most compelling challenges facing educators currently (Garcia, Arias, Harris, & Serna, 2010; Gargiulo & Metcalf, 2010; Gay, 2010; Hollins & Guzman, 2005; Nieto & Bode, 2008). Irrespective of students' academic ability or linguistic, ethnic, religious or cultural backgrounds teachers need to be skilful in providing rich learning experiences. Placing poorly prepared teachers in classes where they are not sufficiently skilled or equipped to consider students' cultural backgrounds in their teaching can yield negative educational outcomes (Orfield & Lee, 2004; World Development Report, 2018).

Inquiry-based teaching methods recognise and value the diversity of students' backgrounds and abilities. Inquiry teaching models such as Roger Bybee's 5Es model of engage, explore, explain, elaborate and evaluate (Bybee, 1997) provide opportunities for science students to ask questions and work collaboratively with their peers to generate novel solutions using their science content knowledge. With expert teacher input, students are able to develop their scientific process skills and understandings.

Diversity in India

India is the second most populous country in the world with around 1.35 billion people. Furthermore, India is geographically and politically divided into 28 states and seven union territories, and within these divisions exist several more subdivisions in terms of caste, regions, languages, religions, socio-economic classes, and gender. India is linguistically diverse, there being 22 official languages and over 100 non-scheduled languages as listed in the Constitution. According to the Multi-dimensional Poverty Index (MPI), developed by United Nations Development Programme (UNDP), which includes ten indicators such as, education, health and standard of living, about 54% of India's population is poor (UNDP, 2016).

Four of the world's religions originated in India, namely Hinduism, Jainism, Buddhism, and Sikhism. Islam and Christianity are two of the other major religions followed widely in India. Hinduism is practised by the majority of the people (79.8%), followed by Islam (14.2%), Christianity (2.78%) and Sikhism (2.08%) (Government of India (GOI), 2011).

In India, the sex ratio is 933 females per thousand males. This ratio is better in rural areas (946) and worse (900) in urban areas (GOI, 2011). Poverty, social inequalities and gender relations intersect in different ways in different regions (Ramachandran, 2009) and hence gender needs to be viewed within the larger social and regional context. The heterogeneity and diversities in India pose a challenge to educational development which is trying to address an extremely large population with complex identities and relations.

Educational Policies Addressing Diversity

Formal education in India is a hierarchically structured system from Kindergarten to university, including institutions of technical and professional education and training. Government requires that up to a given level, all students, irrespective of caste, religion, location or sex, have access to education of a comparable quality. While the national system of education aims at a common educational structure, constitutional provisions, educational policies and programmatic interventions have strived to address challenges posed by diversities that characterise the country and its people. Around 260 million children are enrolled in more than 1.5 million schools (Years 1–12), across 36 states and union territories, with about 8 million teachers (in public and private schools), the Indian education system is one of the largest educational systems in the world and very complex (School Education in India, 2014–2014). As per the Right to Education 2009, schooling is supposed to be free and compulsory for 6 to 14-year-olds in India.

Most matters related to school education, including curriculum, were under the jurisdiction of the State governments until 1976 and the role of the Central Government was restricted to providing guidelines on policy issues. In 1976, the Constitution was amended, whereby legislative powers related to education were given to the Central Government (GOI, 1986).

After Independence in 1947, the concerns of education articulated during the freedom struggle were revisited by the National Commissions, the Secondary Education Commission (GOI, 1952–1953) and the Education Commission (GOI, 1964–1966). The National Policy on Education (NPE) was developed in 1968, followed by a comprehensive review of education. The NPE prioritised science and technology, and wanted science and mathematics to be integral components of education till the end of schooling (GOI, 1968).

In 1986, the NPE emphasised the elimination of female illiteracy and advocated participation of women in vocational, technical and professional education at all levels (GOI, 1968). The Central Advisory Board of Education (CABE) which was introduced in 1992 modified NPE 1986 and widened access to secondary education and emphasised enrolment of girls, Schedule Castes and Schedule Tribes, particularly in science and vocational streams. Computer literacy in secondary schools and equipping children with technological skills were also key policies. The NPE proposed a national curriculum framework to help in the evolution of a system of education that would address India's diversity while maintaining a common core of values along with academic components (GOI, 1992).

In accordance with the NPE 1968 and 1986, school education comprises of 12 years of schooling. This includes eight years of primary education and two years each of secondary and higher secondary education. There is a high degree of uniformity in the pattern of educational structures within a particular State or Union Territory and a broad consensus has emerged for adoption by all States (GOI, 2000).

The Ministry of Human Resource Development (MHRD) looks after the Departments of School Education and Higher Education. The main reason for having these departments as a part of the MHRD is to ensure that education does not operate in isolation but functions as an integral part of the entire system. The National Council of Educational Research and Training (NCERT) assist and advise the MHRD and also prepare and reviews school curricula. The State Councils of Educational Research and Training (SCERTs) aid State governments in formulating and implementing policies, programmes and innovations in school and teacher education. The Central Board of Secondary Education (CBSE) prescribes courses and syllabi, organises teacher orientation programmes and undertakes development and publication of textbooks.

National Curriculum Framework

For the sake of uniformity of standards and for national identity, the NCERT in 1975, developed a framework for a common curriculum (The Curriculum for the Ten Year School: A Framework, NCERT, 1975). Curriculum was defined as the sum total of all the deliberately planned educational experiences provided to a child by the school (NCERT, 1975). However, the implementation of this curriculum was uneven and there was a mismatch between the curriculum objectives and the actual experience in the classroom. This resulted in disparities in the standards of education achieved by school students in different parts of the country. As a consequence, the NCERT in 1988 brought out a document, National Curriculum for Elementary and Secondary Education: A Framework, (NCERT, 1988). This document focused on providing equal educational opportunities to all students, not only in terms of access to educational facilities, but also in the conditions for success; a $10 + 2 + 3$ structure of education; and minimum levels of learning norms for each stage of education.

The National Curriculum Framework (NCF) (2005) at present is the operational guide for school education. It reflects the collective socio-political aspirations of the whole society and plays a significant pedagogical role in directing teachers to choose the content and methods of instruction. According to the NCF (2005) ‘the curriculum is a conceptual structure for decision making as opposed to a layout of what is to be done in the classroom. It not only organises different elements of education, but also makes connections between them’ (p. 32). Some of the main recommendations of the NCERT 1975 document have had a direct bearing on the teaching of science, its syllabi and textbooks. According to NCF (2005):

> At the primary stage the child should be engaged in joyfully exploring the world around it. The objectives at this stage are to nurture the curiosity of the child about natural environments, artefacts and people, to have the child engage in exploratory and hands-on activities, to acquire basic cognitive and psycho-motor skills; to emphasise design and fabrication, estimation and measurement as a prelude to development of technological and quantitative skills of later stages; and to develop basic language skills of speaking, reading and writing for science (p. 67).

The NCF recommends the pedagogical use of activities and experiments at the primary levels as the main method for students to acquire scientific concepts. These activities include group work, class discussions with peers and teachers, student and teacher surveys, organisation of data and their display through exhibitions in schools and the community. At the secondary stage experimentation is an important tool to discover and verify theoretical principles. This stage involves working on locally significant projects in science and technology. Science is introduced as separate disciplines of physics, chemistry, and biology at the upper secondary stage. At this stage, emphasis is placed on experiments, project-based learning, and history of science to understand key concepts of science. Chunawala and Natarajan (2012) note that despite theoretical policy, in practice the situation is very different and most teaching is very traditional, teacher-centred and didactic.

Science Inquiry Teaching

Inquiry teaching envisages that students participate in the processes of questioning, investigating and solving real-life questions through individual or group co-operation. Science experiments play an important role in developing students’ fundamental laboratory techniques, scientific inquiry experience, thinking ability towards more abstract thinking processes, and correct attitudes (National Research Council, NRC, 2000). To develop students’ problem-solving skills, independent thinking, critical thinking, and willingness to explore new ideas, the perspective of constructivism on experimental instruction has been highlighted by science educators and researchers (Reigosa & Jimenez-Aleixandre, 2007). From the perspective of constructivism, an individual learner’s cognitive structure regarding a topic must be personally actively constructed instead of being transmitted by a teacher. Inquiry teaching has been shown to promote effective student learning in science, deeper understanding and greater integration and internalisation than traditional didactic, memory-oriented approaches to learning (Gaddis & Schoffstall, 2007; Germann, Haskins, & Auls, 1996; Rudd, Greenbowe, Hand, & Legg, 2001).

There are two main types of inquiry-based teaching: teacher-guided structured inquiry and student-directed open inquiry (NRC, 2000). During teacher-guided structured inquiry-based learning, the students receive complete instructions; the learners investigate teacher provided questions through a prescribed procedure and are led to a predetermined discovery. With student-directed open inquiry-based learning, students select a wide variety of inquiry questions, design their own experimental procedures, and make their own decisions at each stage of the inquiry process (Zion & Sadeh, 2007). A number of studies indicate that teacher-guided structured inquiry-based learning is insufficient for developing students' higher-level thinking (Berg, Bergendahl, Lundberg, & Tibell, 2003). In contrast, student-directed open inquiry-based learning is time-consuming and difficult to manage. Furtak (2006) pointed that it is difficult for teachers to maintain an atmosphere that encourages student-directed open inquiry while facilitating guided inquiry. Also, empirical studies have shown that students do not always embrace student-centred approaches (Kirschner, Sweller, & Clark, 2006; Klahr & Nigam, 2004; Vernon & Blake, 1993).

Method

The case studies reported here describes the development, implementation and evaluation of a three-day professional development (PD) workshops conducted with Indian middle school (Grade 6–8) science teachers in western and central, India. Author developed and implemented the PD with four groups of science teachers. The primary aims of the program were to:

- Clarify links between socio-cultural diversity in classrooms, choice of inquiry teaching methods and science content
- Introduce teachers to science inquiry strategies and activities suitable for use in middle school science classrooms
- Evaluate the impact of the PD through quantitative and qualitative data.

The primary resource used in the PD was the *Science by Doing* professional learning resources (Australian Academy of Science, 2011). The professional learning resources comprise five DVDs. The DVDs include background information on teaching strategies and resources and exemplars of teachers modelling the strategies and activities.

Participants

Each PD was attended by 30 science teachers. In western India, participating teachers represented 23 different schools and 30 schools in central India (two from each of the selected schools). The participants' teaching experience varied from one year to 31 years with a mean time of 8.89 years. Teacher qualifications were varied e.g. high school graduate, Bachelor's degree, Master's degree and 10 participants had Ph.D. degrees. 95% of teachers were females and participants represented diverse religious faiths namely, Hindu, Muslim, Christian, and Jain.

Delivery of the Professional Development

The three-day PD was comprised of nine sessions with three sessions being delivered each day. A summary of the nine sessions is presented in Table 1. All sessions were conducted in English. The sessions were collaborative and interactive. Teachers worked in groups of three or four and had the opportunity to practice the strategies and activities and discuss their usefulness in their particular teaching environment.

Data Sources

All nine sessions were videotaped for evaluation purposes and participants were invited to complete a questionnaire before and after the PD. The pre-PD questionnaire had three sections. The first comprised questions about the participants' background such as subjects taught, qualifications, teaching experience and gender. The second section had 4 questions relating to the relevance of the PD to the teachers and data for these questions were collected on a five-point Likert scale. The third section was a qualitative free response question to gain insights into participants' expectations about the workshop. The post-PD questionnaire had a similar structure to the pre-workshop questionnaire. However, the question in the third section was about the extent to which the PD had met participants' expectations.

Informal interviews were conducted with ten teachers (five from each group) to gain insights into the PD needs of Indian science teachers. One member of the organising team observed all the nine sessions and took field notes.

Table 1 Summary of three-day professional development program

Day	Session	Topic	Contents
1	1	Introduction, overview and aims	• Introducing to group • Writing down expectations from the workshop • Formative assessment of pre-existing conceptions about science inquiry
	2	Science inquiry-What is it?	• Definition of science inquiry • From a given set of cards sort statements into inquiry and traditional teaching; • DVD Inquiry-based Teaching (The Rule of the Seesaw) (AAS)
	3	Student learning and 5E model of learning	• Alternative conceptions and its examples • Probing teachers' alternative conceptions • Water droplet and investigating cohesion activity
2	4	Inquiry-based teaching strategies	• Brainstorming, concept mapping, gallery walk, envoy, jigsaw and predict-observe-explain (POE) • Activities using POE, brainstorm, concept map and gallery walk
	5	Nature of science	• Science as a way of knowing • Box and rope activity
	6	Investigating	• Parts of a scientific investigation • Investigating—what is it? • Investigating bounce height of different balls and effect of surface
3	7	Discussion and questioning	• Watch DVD Effective questioning (AAS) • Introducing Blooms taxonomy, participants develop questions on different levels of thinking
	8	Diversity and science education	• Diverse nature of Indian population • Bowl and candy activity
	9	Assessment	• DVD Assessment (AAS) • Assessment types and items

Results

The second section of the questionnaires (pre and post) asked teachers to respond to the following questions below:

1. How relevant is/was the agenda of this workshop to the Indian Science Curriculum?
2. How relevant is/was the workshop to your professional needs?
3. How much do you think this workshop will help increase the professional capacity of your school for catering to the diverse needs of students?
4. How timely is/was this workshop for the planning of the next year's teaching in your school?

Teachers used a five-point Likert scale to record their responses. As can be seen in Table 2, out of four quantitative questions on perceived (Pre) and actual (Post) relevance of the workshop to participants, differences on two questions were found to be statistically significantly different. For question one, the difference is significant at $p < 0.001$ level and at $p < 0.05$ for question four. Medium to large effect sizes (0.47 for Q1 and 0.30 for Q4) are further confirming this finding.

Teachers' Expectations of the PD

The third qualitative section of the pre-workshop questionnaire asked participants, *What do you expect to gain most from this workshop*?. Responses to this question and interview data from the ten teachers were tabulated and entered into an SPSS text analyses package and themes derived. Grounded theory (Corbin & Strauss, 1990) was used to identify four themes. They were: using inquiry in an Indian context; using inquiry to generate knowledge; using inquiry to cater for diversity; and usefulness of PD. Teacher comments to exemplify each of the themes are presented below. Note that quotes are presented as written and teachers' grammar has not been corrected.

Table 2 Teachers perceived relevance of the PDP

Question	Mean		S D		*t*	Effect size *r*
	Pre	Post	Pre	Post		
Q1	3.94	4.31	0.83	0.71	5.04***	0.47
Q2	4.52	4.60	0.67	0.63	0.78	0.12
Q3	4.29	4.35	0.61	0.63	0.52	0.09
Q4	4.31	4.53	0.79	0.65	2.11*	0.30

$N = 90$, ***$p < 0.001$, *$p < 0.05$

Using Inquiry in a Indian Context

The main expectation expressed by teachers before the PD was how to use inquiry teaching in Indian classrooms. This is reflected by the following comments:

> I would like to know how inquiry method of teaching can be adopted in Indian context. I would also like to know other peoples idea about inquiry method of teaching in science classroom.

> I expect to learn and understand how to integrate the new pedagogy in school where student teacher ratio is 1:80 and infrastructure is limited, how to integrate pedagogy with curriculum considering the limitation of time frame, how to get success in the first shot after introducing new pedagogy, how to understand various other pedagogies related to science education and bring a 180 degree change in Indian school scenario.

Using Inquiry to Generate Curiosity

The second most common theme was that teachers wished to learn about new and interesting methods of teaching. Teachers were keen to change their existing ways of teaching as indicated below.

> New techniques, methods to handle student's new ways to help students develop more interest for science subjects

> How to teach in different way with lots of activity & to make science from boring to interest in the classroom

Using Inquiry for Diversity

Teachers expressed concerns about the diversity of student ability within their classes and wanted to develop strategies to cater to students with varied intellectual abilities.

> I expect to learn different approaches to teach considering the diversity of the students like different intelligences and different learning styles, as well as students with special needs.

Some teachers specifically asked for exemplars that would be suitable for children in rural schools.

> How to make successful activity-based learning in rural areas, how to increase teachers capacity for catering to the diverse needs of students.

Usefulness of PD

A theme not directly related to science inquiry or diversity was a desire that there would be learning that was relevant to their teaching. This desire was based on past experiences of PD where the material presented was not suited to their needs.

> Many other workshops explain & talk about interdisciplinary skills, relating diff subjects, but it doesn't help always- whatever we learn in Bed and in other workshops -why it does not work in classroom environment.
>
> I am apprehensive about the application in the classroom and if it will fulfil the curriculum requirements. So I am hoping to clarify my doubts.

Workshop Satisfaction

In the post PD questionnaire and the informal interviews, teachers were asked, *How could the workshop be improved to better Indian teacher's needs*?. There were three main themes that emerged from this coded data. They were: satisfaction with the workshops; including examples from Indian curriculum and textbooks; and catering for large classes.

Satisfaction with the Workshops

Despite the initial concern of some teachers (in the Pre-PD questionnaire) that this was 'just another PD', a majority of teachers thought that they had gained a lot from their participation. Comments endorsing this view included:

> I think this workshop was conducted greatly. No need of further improvement. Enjoyed the activities. Thanks for organising this great workshop.
>
> Workshop was well planned and well managed. DVD's were good to understand. Activities were good and enjoyed them; we can also use this with our children in the classroom.
>
> I do recommend this type of workshop for Indian School Teachers. Only thing is that there should be a culture of teaching that more and more urban and rural schools should adopt this method. Workshop was good in all respect. I do not think any improvement.

Include Examples from Indian Curriculum and Textbooks

Overall the teachers were satisfied with the content, organisation and delivery of the PD. However, they sought examples from the Indian Curriculum and textbooks.

> Being a collaborative approach the workshop needs to talk about present Indian scenario too. Though we dealt with diversity we could have also taken a few classroom behaviour problems. Few activities could have been designed with Indian curriculum.
>
> Modify the models/conduct pilot projects in state board school where the classroom conditions are adverse/modify models on the basis of feedback/experiences encountered during the pilot project/conduct another project to verify its effectiveness and finalise training modules for Indian Schools.
>
> The workshop could be related to textbook chapters/materials that are there in the book.

Catering for Large Classrooms

Another theme arising from teachers' comments was a need for strategies that can be used in large classes using inquiry teaching.

> Discussion on how to apply inquiry method for large classes should be there
>
> The workshop helped to reinforce many concepts which I was aware of and also got to learn new concepts too. Still I am doubtful about how this implementation in a large classroom.

Discussion

In this study, a PD program was developed based on the Australian Academy of Science, Science By Doing professional learning resources. The PD program covered many aspects of science inquiry including designing inquiry-based lessons, establishing prior knowledge, motivating and engaging students, co-operative group work, scientific investigating, questioning and assessment (i.e., diagnostic, formative and summative). Although the PD sessions were prepared in advance by the science educators, the questionnaire results indicated that the main teacher expectations of the PD were to find out how to use science inquiry and cater for diversity. The quantitative findings indicate that the program was highly relevant to the teachers' needs ($p < 0.001$) and timely in preparation for the school year ($p < 0.05$).

Overall teachers were satisfied with the PD workshops. However, there were two aspects where the needs of some teachers were not fulfilled. The first aspect was to include examples from the Indian curriculum and/or textbooks. It appears that teachers in some schools felt compelled to 'teach to the text' and would value activities that exactly matched the content of the textbook. In future workshops, activities (e.g., Predict-observe-explain, concept mapping) will be matched to particular sections of the textbooks.

The second aspect that was not sufficiently addressed was catering for large numbers of students. During the workshop, we discovered that some teachers taught in schools with class sizes of up to 80 students of varying ability. On visiting three schools after the PD we found out that not only were the classes large but the classrooms were small with fixed desks and few resources making co-operative group work and practical activities challenging. However, we did observe one of the participants using a 'think-pair-share' and group work in such a classroom.

A limitation of this study is that we are unaware of the extent to which teachers have actually made long-term changes in their teaching. Although the authors are administering a follow-up questionnaire to the participants we are not able to observe the teachers.

Conclusion

This paper reports on the development, implementation and evaluation of two 3-day science inquiry PD's for 90 Indian middle school science teachers in Mumbai and Gwalior. In planning the program the science educators aimed to introduce the teachers to strategies and practical activities that could be readily used in culturally diverse classrooms. Science inquiry is a mandated requirement in the national Indian curriculum. Overall, the teachers who participated in the PD were satisfied with their experiences. However future PD is needed that focuses on science inquiry with large classes of varying ability and few resources.

References

Australian Academy of Science. (2011). *Science by doing*. Retrieved from https://www.sciencebydoing.edu.au/.

Berg, C. A., Bergendahl, V. C., Lundberg, B., & Tibell, L. (2003). Benefiting from an open-ended experiment? A comparison of attitudes to, and outcomes of, an expository versus and open-inquiry version of the same experiment. *International Journal of Science Education, 25*(3), 351–372.

Bybee, R. W. (1997). *Achieving scientific literacy: From purposes to practical action*. Portsmouth, NH: Heinemann.

Chunawala, S., & Natarajan, C. (2012). A study of policies related to science education for diversity in India. In *Annual Meeting of National Association for Research in Education*, *held in Indianapolis,* 25–28 March.

Corbin, J. M., & Strauss, A. L. (1990). Grounded theory research: Procedures and evaluative criteria. *Qualitative Sociology, 13*(1), 3–21.

Department of Jobs and Small Business. (2017). *Industry employment projections, 2017 Report*, p. 2.

Furtak, E. M. (2006). The problem with answers: An exploration of guided scientific inquiry teaching. *Science Education, 90*(3), 453–467.

Gaddis, B. A., & Schoffstall, A. M. (2007). Incorporating guided inquiry learning into the organic chemistry laboratory. *Journal of Chemical Education, 84,* 848–851.

Garcia, E., Arias, M. B., Harris, M. N. J., & Serna, C. (2010). Developing responsive teachers: A challenge for a demographic reality. *Journal of Teacher Education, 6*(1–2), 132–142.

Gargiulo, R. M., & Metcalf, D. (2010). *Teaching in today's inclusive classrooms: A universal design for learning*. Belmont, CA: Wadaworth.

Gay, G. (2010). Acting on beliefs in teacher education for cultural diversity. *Journal of Teacher Education, 6*(1–2), 143–152.

Germann, P. J., Haskins, S., & Auls, S. (1996). Analysis of nine high school biology laboratory manuals: Promoting scientific inquiry. *Journal of Research in Science Teaching, 33*(5), 475–499.

Government of India. (1952). *Secondary education commission report.*

Government of India. (1964–1966). *Report of education Commission*.

Government of India. (1968). *National policy on education-1968*. New Delhi: Ministry of Education.

Government of India. (1986). *National policy on education-1986 and programme of action 1986*. New Delhi: Ministry of Human Resource Development.

Government of India. (1992). *Report of the CABE Committee on Policy*. New Delhi: Ministry of Human Resource Development.

Government of India. (2000). *Education for all: The year 2000 assessment report*. New Delhi: Ministry of Human Resource Development.

Government of India. (2011). *Provisional population totals*. India: Retrieved from http://www.censusindia.gov.in/2011-prov-results/data_files/india/paper_contentsetc.pdf.
Hollins, E. R., & Guzman, M. T. (2005). Research on preparing teachers for diverse populations. In M. Cochran & K. M. Zeichner (Eds.), *The report of the AERA panel on research and teacher education* (pp. 477–548). Mahwah, NJ: Lawrence Erlbaum Associates.
Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry based teaching. *Educational Psycologist, 41,* 75–86.
Klahr, D., & Nigam, M. (2004). The equivalence of learning paths in early science instruction: effects of direct instruction and discovery learning. *Psychological Science, 15*(10), 661–667.
National Council of Educational Research and Training. (2005). *National curriculum framework*.
National Research Council. (2000). *Inquiry and national science education standards: A guide for teaching and learning*.
NCERT (1975). *The Curriculum for the ten year school: A framework*. New Delhi.
NCERT. (1988). *National curriculum for elementary and secondary education: A framework*. New Delhi.
Nieto, S., & Bode, P. (2008). *Affirming diversity: The sociopolitical context of multicultural education* (5th ed.). Boston, MA: Pearson.
OECD. (2012). *PISA 2009 technical report*. OECD Publishing.
Orfield, G., & Lee, C. (2004). *Brown at 50: King's dream or Plessy's nightmare?*. Cambridge, MA: The Civil Rights Project, Harvard University.
Ramachadran, V. (2009). *Education for all-mid decade assessment: Towards gender equality in education*. New Delhi.
Reigosa, C., & Jimenez-Aleixandre, M. P. (2007). Scaffolded problem-solving in the physics and chemistry laboratory: Difficulties hindering students' assumption of responsibility. *International Journal of Science Education, 29*(3), 307–330.
Rudd, J. A., Greenbowe, T. J., Hand, B. M., & Legg, M. J. (2001). Using the science writing heuristic to move toward an inquiry-based laboratory curriculum: An example from physical equilibrium. *Journal of Chemical Education, 78,* 1680–1686.
School Education in India. (2014–2015). http://www.dise.in/Downloads/Publications/Documents/U-DISE-SchoolEducationInIndia-2014-15.pdf.
Shrinivasan, R. (2010, July 15). 55 percent of India's population poor: A report. *Times of India.*
Sobel, D. M., Gutierrez, C., Zion, S., & Blanchett, W. (2011). Deepening culturally responsive understanding within a teacher preparation program: It's a process. *Teacher Development: An International Journal of Teachers' Professional Development, 15*(4), 435–452.
Science by Doing. (2010). *Engaging students with science*. Canberra: Australian Academy of Science: Retrieved from http://science.org.au/sciencebydoing/.
United Nations Development Programme (UNDP). (2016). *Human development for everyone*. Retrieved from http://hdr.undp.org/en/2016-report.
Vernon, D. T., & Blake, R. L. (1993). does problem-based learning work? A meta-analysis of evaluative research. *Academic Medicine, 68*(7), 550–563.
World Development Report. (2018). *Learning to realize education's promise*. Retrieved from https://www.worldbank.org/en/publication/wdr2018.
Worldometers. (2019). *India population*. Retrieved from https://www.worldometers.info/world-population/india-population/.
Zion, M., & Sadeh, I. (2007). Curiosity and open inquiry learning. *Journal of Biology Education, 41*(4), 162–168.

Connecting Formal Science Classroom Learning to Community, Culture and Context in India

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Abstract The perception of separation between school and home/community is related to diminished achievement in school and lack of motivation to learn STEM subjects. The National Council of Educational Research and Training (NCERT) is among many research organisations that have strongly recommended that schools bridge the disconnect between school-based knowledge and learners' everyday knowledge. We designed the SPIRALS (Supporting and Promoting Indigenous and Rural Adolescents' Learning of Science) curriculum to bridge this gap between formal science and students' everyday lives. SPIRALS helps students explore community-based practices to learn about science, environmental sustainability and systems thinking. We implemented the SPIRALS curriculum in a private, urban, English medium school in Western India with approximately 315 students and their four teachers, 214 (or 68%) of whom also participated in the research from which our conclusions are drawn. Our findings about program impacts rely upon analysis of interviews with teachers and students, as well as student work, and conference participation assessment surveys distributed after a capstone experience at which students present their work. This chapter describes our findings about how students learned science, environmental sustainability, and systems thinking through engagement with community-based practices. We also discuss the process of how the SPIRALS approach worked in India and how it could be expanded into a broader learning model across different socio-cultural contexts within India.

Introduction

In an age when environmental challenges are threatening human survival, engaging youth in science education that focuses on environmental sustainability is an urgent

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need (Stevenson et al., 2013). Environmental challenges such as climate change, natural resource management, energy and health problems put pressure on scientists and engineers to come up with solutions (Fields et al., 2014; Hestness, McDonald, Breslyn, McGinnis, & Mouza, 2014). The latest report by the Intergovernmental Panel on Climate Change (IPCC, 2013), suggests that there is a critical need to address environmental challenges through the lens of environmental sustainability and help the public understand how human activities can disrupt or enhance environmental conditions. Educators likewise need to design teaching approaches that help young learners understand environmental challenges through the lens of environmental sustainability (Harmon, 2017; Kern, Honwad, & McClain, 2017).

The term environmental sustainability has been used in science education literature to highlight the balance between resource use for economic prosperity and environmental health conditions (Feinstein & Kirchgasler, 2015). Environmental sustainability is an interdisciplinary science concept that deals with how human activities at local and global levels alter the equilibrium of environmental conditions (Barry, 1994; Gough, 2002; Lozano, 2008). Many countries in the world have incorporated topics related to environmental sustainability in their science curricula (Next Generation Science Standards, Lead states 2013). Thus, environmental sustainability is a crucial topic that science education curricula around the world need to address.

Environmental sustainability as a discipline tries to understand local and global level environmental challenges. There are countries in the world that have greater environmental challenges, in the form of human activities that lead to pollution, carbon emissions, and excess resource use (Carley & Christie, 2017). India, for instance, is one of the top five carbon emitters in the world and problems like air pollution have started to severely impact the health of its population (Schultz, Kumar, & Gentleman, 2017). While people in New Delhi currently don masks to protect themselves from air pollution, any long-term solution to the problem will require future generations of Indians to be motivated and engaged in scientific endeavours to address environmental sustainability issues more comprehensively (Muttarak & Lutz, 2014). Sustaining interest in science amongst youth is especially crucial for countries such as India because although environmental problems, such as pollution and unsustainable resource use, have a global impact, they need resolution at a local level that requires long-term solutions based on scientific knowledge (Ramadoss & Poyyamoli, 2011). This is another reason why environmental sustainability needs to be a part of the Indian science education curriculum.

The scientific approach of observation, research question development, data collection, analysis, and conclusion can promote a thorough understanding of how components of a human activity at the local community level can affect environmental conditions at both local and global levels. In the United States, the Next Generation National Standards highlights the importance and relevance of connecting everyday life activities to these scientific processes (Penuel, Harris, & DeBarner, 2015). However, students and teachers have a difficult time recognising that everyday local enactments that focus on environmental sustainability may be grounded in the scientific process (Folke, Biggs, Norstorm, Reyers, & Rockstorm, 2016; Kohtala, 2015). For example, in many villages and cities across India everyday problems such as water scarcity and energy conservation can be addressed using a scientific approach. Rainwater harvesting is an approach that is grounded in the scientific process and has been used in India extensively to help with water conservation. Thus an approach grounded in science such as the one mentioned in the above example can provide solutions to local problems generated from community-level activities that affect local and global environmental conditions. In India, environmental sustainability is regarded as an interdisciplinary endeavour that cuts across social science and environmental sciences (Jackson, 2003). Even though environmental sustainability is taught in schools across India, it is not a scientific subject that holds the same prestige as physics, chemistry, or biology (Jackson, 2002). As Jackson (2003, p. 97) describes, the state of the environmental sustainability curriculum in India in general 'has been an ad hoc exercise in which environmental subject matter has not been integrated into the existing text, but simply added on'. Thus even though students in India show high levels of interest in science the focus is on subjects such as physics, chemistry, or biology and not on environmental sustainability or problem-solving.

Current research has shown that Indian students are motivated to learn about science-related subjects because of the social pressure of finding a good job (Iyer, 2015). Tackling environmental sustainability challenges within their communities require Indian youth to realise the benefits of applying scientific knowledge and skills to community problems instead of thinking about science merely as a pathway to employment.

Science Education in India

India is the world's biggest democracy and is socio-culturally one of the most diverse nations in the world, with 122 different languages spoken across approximately 1.3 billion people (Guha, 2017). The country confronts several broad challenges in the process of designing and developing effective approaches to environmental sustainability education (Blum, 1987) that are caused not only by the historical impact of colonisation but also by continuing globalisation (Mochizuki & Bryan, 2015).

The impact of colonisation can be observed within the educational policies of the country, for example, the emphasis on the indispensable value of English as a language of instruction as well as a vocational pathway (Dhar, 2012). Thomas and Waters (2015) explain

> Access to the resources and bodies of scientific knowledge captured in English language literature are also influential in promoting the use of English. Fueled by these beliefs, the Indian education has seen a significant paradigm … towards a system that is deliberately implementing English as the medium of instruction in public and private schools countrywide. (p. 7)

Consequently, most of the science instructional approaches in Indian schools are modelled on Western teaching practices (Kingdon, 2017). Moreover, as previously described, student enrolment in science subjects may be motivated by economic opportunities rather than an intrinsic motivation for acquiring science knowledge and engaging in the scientific process (National Council of Applied Economic Research, 2005). Sustaining interest in science (beyond potential employment) has thus been a challenge that is acknowledged by Indian researchers. Since solving community-level environmental problems and working toward a sustainable future requires citizens to maintain a genuine interest in science, educators must employ novel approaches to enhance student interest (Wildschut, 2017).

In India, a cultural dissonance between school and home/community is related to diminished motivation and lack of interest to learn science topics for purposes other than employment. Researchers have demonstrated that student interest in science can be generated and maintained if science knowledge can be made relevant to their everyday lives (Banks, 2015). Connecting science to students' everyday lives can also make students reflect on science as a way to solve community-based problems and create a meaningful attachment to their community. The National Council of Educational Research and Training (NCERT, 2005) in their latest publication for science teachers, recommends the following approach to teaching science in formal classrooms across India, 'For science to make sense to the students and to use their life experience, we need to give them the opportunity to relate the two' (p. 18). The NCERT is among many research organisations that have strongly recommended that schools need to bridge the disconnect between school-based knowledge and learners' everyday lives. Even though the NCERT has stressed the need to engage students by valuing their everyday knowledge, the Indian science education community has yet to adapt teaching approaches that would enable learners to construct knowledge based on their everyday life experiences (Ramasami, 2009).

Given the current need to design and develop an environmental sustainability curriculum that addresses local needs, sustains student interest, and counters the historical and contemporary challenges to the education system in India, we adopted a community-based science learning approach with middle school students in India. The SPIRALS (Supporting and Promoting Indigenous and Rural Adolescents' Learning of Science) curriculum focuses on having students examine local community practices that exist in students' everyday lives. The SPIRALS curriculum seeks to move students away from a science-learning environment that emphasised learning science exclusively to get a good job. The curriculum connects science learning to students' everyday lives and focuses on community-based activities in order to enhance student understanding of how science is an integral part of their lives and communities beyond the workplace.

SPIRALS, grounded in ideas of community-based science learning approaches (Lotz-Sisitika, Wals, Kronlid, & McGarry, 2015), is similar to science curricular approaches that have been observed to impact students positively across a few places in India previously (Sonowal, 2008). By focusing on local community issues, the SPIRALS curriculum also creates a counter-narrative to the globalised Euro-American environmental perceptions that are observed within the majority of environmental sustainability curricula across India (Pande, 2001, 2002; Siddiqui & Khan, 2015). Continuing in this vein, in this chapter, we explore how the SPIRALS curriculum uses a community-based science approach to address some of the urgent needs that focus on environmental sustainability and how this approach may help sustain student interest in science and can lead to action toward environmental sustainability.

SPIRALS as a Community-Based Science Model

The separation between the science knowledge that communities use and the ways that science is presented in a traditional classroom setting inspired the development of the SPIRALS curriculum. The goal of the SPIRALS approach is to use the context of local communities to demonstrate how scientific understanding exists in the everyday experiences of youth and how community-based knowledge adds critical knowledge to sustainability science. The creation of the SPIRALS curriculum was the result of collaboration between the University of New Hampshire and the University of New Hampshire Cooperative Extension 4-H program. SPIRALS was funded through a United States National Science Foundation grant developed to help young learners (11–14 years old) from indigenous and rural communities succeed in and connect with science, and encourages learners to explore the rich traditional ecological knowledge that exists within their communities. Educators have implemented the SPIRALS curriculum in various educational settings; one site in India and ten in the United States, including one site in Hawaii. The use of diverse settings was an essential test of the community-based curriculum which was designed to be adaptive to the needs of different grade levels, communities and environments such as afterschool programs, and more traditional school classrooms, as well as school immersion experiences.

The SPIRALS approach to community-based science learning is centred on the perspective that all children have useful knowledge acquired by being embedded within richly knowledgeable communities. These funds of knowledge are 'historically accumulated and culturally developed bodies of knowledge and skills essential for household or individual functioning and well-being' (p. 133). It also includes elements from other community-based science learning (Bouillion & Gomez, 2001; Bang & Vossoughi, 2016), complex systems thinking (Resnick & Wilensky, 1998), as well as culture and learning models (Banks, 2010).

The traditional roles of learner, teacher, school and community are modified to enhance student engagement and learning of sustainability science when the SPIRALS approach is adopted. Learners are able to become explorers of their communities and tap into their unique, individual networks of knowledge and skills within their community members. Teachers become bridges helping students connect their community-based understandings to scientific knowledge and skills. In SPIRALS, every group of students learns about systems thinking, the coupling of human-environment systems, and the principles of sustainability. Schools become active members of their local communities in understanding local community practices and discussing solutions to environmental problems. *Most importantly*, community members can be re-envisioned as sources of data, generating ideas and solutions to the point of being regarded as scientific experts. Community-based science learning promotes the value of learning science beyond vocational ends or a demonstration of academic knowledge.

The SPIRALS curriculum looks at community-based practices and problem-solving that engages students in observing facets of their everyday life as important sources of scientific knowledge generation and application. By connecting science to students' everyday lives, the SPIRALS curriculum provides a way for students to consider that: (1) Science is not limited to classroom lessons and scientific careers but is regularly used for many community activities and within the everyday lives of community members (e.g., water treatment, transportation), (2) Science is necessary to sustain healthy communities and solve community-based environmental issues, and (3) Students, as community members, have the ability to support and enhance the communities in which they live.

SPIRALS in India: The Place, Context and Implementation

We implemented SPIRALS in a private, urban school located in West-central India. The language of instruction in the school was English and the school served students from grade 1 through 12. Over a period of 8–10 weeks, 5th, 6th and 7th grade students participated in this project as part of their science and social science curriculum. The vision of the school was to engage the students with locally-grounded education and therefore SPIRALS was well aligned with the guiding philosophy of the school. Educators in India followed this inquiry-based procedure which encouraged flexibility and choice for both teachers and students:

1. Inquire about an environmental issue in students' communities.
2. Brainstorm with students about how community members deal with the issue.
3. Create a pre-investigation mind map to depict the selected community issue or problem and how to solve it.
4. Develop a means to approach community members to understand the students' issue of interest through community perspectives.
5. Interview, discuss, or observe how communities deal with this issue.
6. Create a post-investigation mind map of how the issue could be addressed or be handled in a 'better' way.
7. Construct a final project sharing student findings about the issue, and different viable solutions to problems.

The context-sensitive SPIRALS curriculum welcomed variances in implementation at different sites in the two participating countries. Implementation of a similar series of steps in research sites in the United States, therefore, focused more on the sustainability of a community practice, while implementation in India focused more on a community challenge and possible solutions. This shift in focus, required a commensurate shift in representations of student learning. Students in the United States created systems maps, or depictions of a sustainable process (e.g. composting), whereas students in India created mind-maps or depictions of related knowledge (e.g. causes and effects of pollution).

In the Indian research site, as a result of step one, the initial inquiry, the 5th and the 6th grade classes chose pollution as a community-based problem to investigate, while the 7th grade classes chose to investigate issues related to community water conservation. During the second step, students explored their current understandings of the issue. For example, 7th-grade students discussed how water is supplied to their community and specifically how the water gets from a reservoir to their homes. Step three involved groups of 2–5 students creating a visual representation, or mind-map, of this knowledge. Teachers examined these maps with students to identify knowledge gaps about their local problem, to plan their investigations, and to identify misconceptions students may have had regarding how local practices interacted to operate as a pollution or water conservation system. These maps also provided a baseline from which to assess student learning at the completion of the project.

In the 5th-grade classrooms, students worked in groups of 2 or 3 to create an initial mind map of how they thought different types of pollution affected their community. Figure 1 presents a pre-investigation mind map which displays some broad ideas about pollution without illustrating students' awareness of which types of pollution most affected their community.

During steps four and five, students prepared for and then participated in community research to further develop their understandings of the local environmental issue.

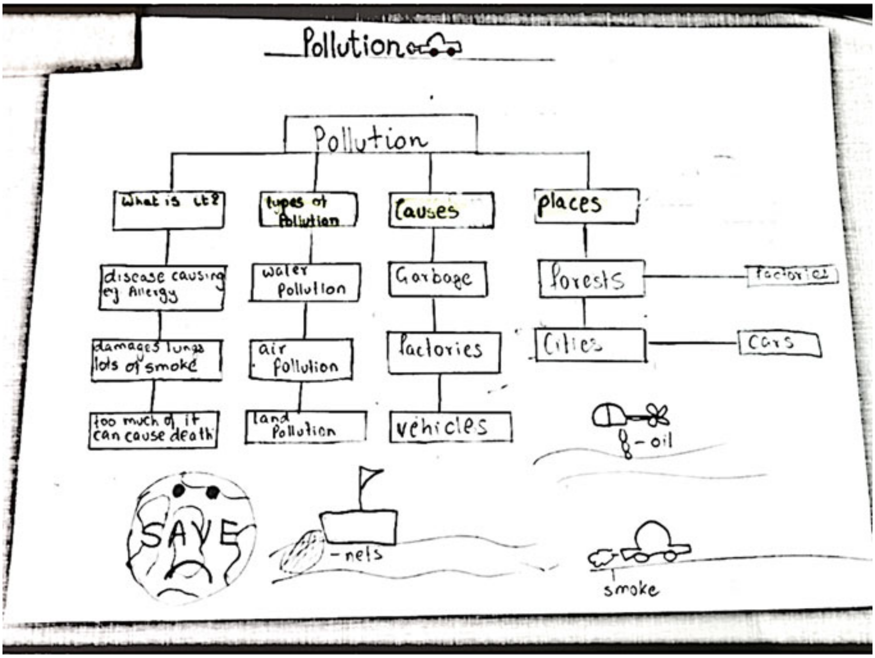


Fig. 1 Pre-investigation mind map

Although the goal of the project was to acquire science knowledge from community-based learning, how students acquired this knowledge differed by educator in the form of interview questionnaires, field observations, newspaper articles reporting on pollution during a local Diwali festival (Festival of lights celebrated annually), internet research, and/or documentaries. For example, the school encouraged the use of a local daily newspaper in its everyday curriculum thus allowing students to access current local topics of interest. Some students in the 5th grade designed interviews to ask their community members about such things as their knowledge of ecological practices, their practices that cause pollution in their daily lives, as well as how their practices could be changed. Figure 2 provides an example of a summary of one student group's questionnaire results.

Meanwhile, the 7th-grade students researched the water supply in their community along with the science behind how the process of filtration works, including components (e.g. people, water, electricity) in their community that contribute to the function of the water supply process and how their own everyday actions contribute to water use sustainability.

During step 6, the 5th-grade students collected and analysed interviews with community members and summarised their findings as reflected in Fig. 2 or in post-investigation mind maps when other data collection methods were used (Fig. 3).

In Fig. 3 the students not only have drawn specific types of pollution that affect their communities the most (air, water, and noise) but also have mapped how pollution is causing specific problems (e.g., 'noise pollution will cause hearing problems among the community members').

The final step of the SPIRALS curriculum is for students to present their findings publicly within their classrooms, school, and/or community. These presentations, as

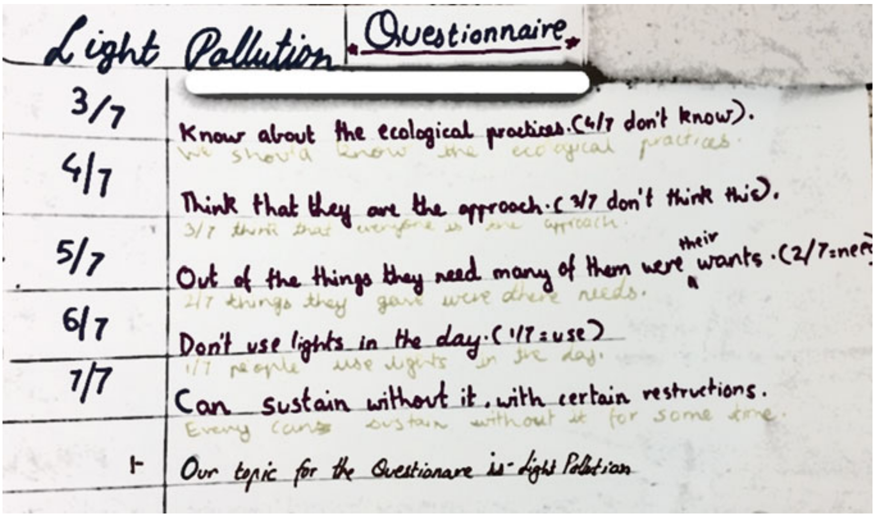


Fig. 2 Summary of questionnaire results from the light pollution group

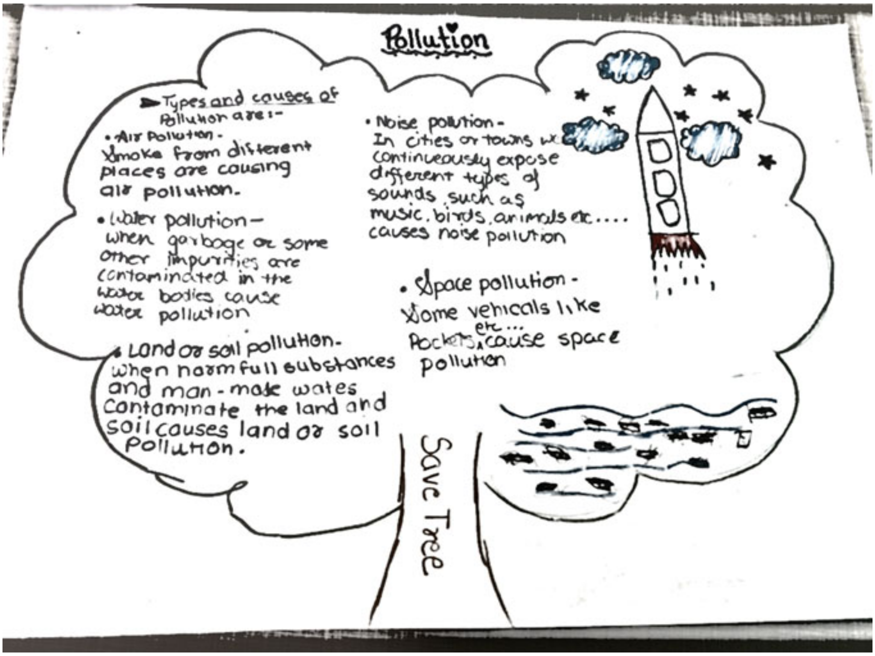


Fig. 3 Post-investigation mind map

with investigation data collection methods and other assignments, varied in format by class (e.g., PowerPoint slide presentations, exhibitions, theatre performances). Both teachers from the fifth grade asked students to propose hypothetical gadgets to address pollution challenges. Student gadgets proposed included an air purifier, garbage blaster, and pollution detector. The 5th-grade students concluded by presenting their findings from the project to their entire school in the form of a poster exhibit. In the exhibit, students displayed the process of how they investigated the problem of pollution in their communities. When exploring garbage management, the 6th-grade teacher asked students to think about how to reuse garbage to create something new and present their findings on garbage management in exhibit format, whereas, students in 7th grade used a street theatre performance to highlight their findings. Street theatre performances are common across different parts of India and are often used to highlight social issues. Thus, the curriculum allowed classes of 5th-, 6th- and 7th-grade students the flexibility to choose topics for investigation, connect topics to students' everyday lives and present their findings in a way that made sense for them. Appendix provides a guide for how to conduct the SPIRALS curriculum in the classroom.

Student Engagement and Learning in an Urban, Private School in Western India

By using a community-based science approach with our students in India, we anticipated that their interest in and motivation for science would increase. As part of our research, we interviewed a subset of 30 students about which aspects of SPIRALS helped them learn the most, which aspects they enjoyed the most, and how they would apply what they learned in the future. Supplementing the interviews was a total of 214 student Conference Participant Assessments (CPA) submitted in response to their final research project exhibitions. The CPA survey was administered during the students' final presentations (at the end of the last unit of the SPIRALS curriculum). The CPA survey was designed to find out student's perceptions of their knowledge about sustainability at the end of the project, and how much they learned from other students' final presentations, as well as students' continued curiosity and intention to behave more sustainably in the future. Analysis of 17 student summative work assignments helped substantiate student CPA reports. Interviews with 3 classroom teachers also provided context for understanding student engagement and demonstration of learning. Evidence from interviews substantiated the predicted improvement in science interest, in addition to the benefits of redefining students' personal conceptions of science learning, and empowering students in their own communities as science learners.

Student Motivation

The impact of using a community-based science approach with Indian students began to emerge from the reports of our students. The interviews with students supported the conclusion that students were excited by their participation and gained new insights into subjects they weren't originally interested in. One student told us, '*So, we were excited because it would be something new, a way of learning, a new way of learning things. So, we thought it would be interesting and it turned out that it was.*' Another student gave an example of how this was the case in describing doing a research project on garbage collection and disposal saying, '*At first I thought that garbage was like yucky and I didn't really want to do research about it but once I started, I thought it was really exciting.*' As we can observe from these quotes students' thinking about science as a part of their everyday lives gravitated from unpleasant to 'exciting' through the use of a novel approach. The students found it interesting that the curriculum connected classroom science learning to problems in their communities. Not only were some students motivated to participate in the program initially, but their interest and engagement was also evident during their learning experiences, as one student reflected, '*I enjoyed the street play, because we got to interact with the crowd.*' This highlights the fact that the direct communication and interaction with the community, that was an integral part of the curriculum, evoked student motivation.

Student Learning

As part of the curriculum, students were engaged in understanding environmental problems of their community. The opportunity to engage deeply in these questions seemed to impact the students' beliefs about themselves as science learners and their views of science itself. As research points out, students often have their prior conceptions of science grounded in beliefs about the utility of science, primarily as a pathway to good jobs. However, after participating in a more community-based science approach, we observed that there was a shift in the way the students thought about the process of conducting science. Students took an active role in discovering the science of their communities, as exemplified by one student who told us, '*I also increased my social skills by interviewing all the society people and I also got to know a lot about the society.*'

The creative and community-specific nature of the SPIRALS curriculum welcomed autonomous implementation. This not only positively impacted teacher motivation, but also invited variability in student products. The four classrooms at the Indian research site, therefore, shared: a flow chart showing how garbage comes from the home, a video of the 7th grade students' street play, and 17 other analysed submissions presented either as posters describing the problem of pollution, or as research reports, that sometimes included findings from community-based data collection efforts. These interviews with community members grounded student research in their daily lives, with examples of positive and negative choices occurring in society. Comparison of the problem description and research reports enabled researchers to confirm the student and teacher reports of student learning provided in survey and interview data.

By taking ownership of their own learning, students were able to demystify the concept of science as exclusive, and gain accessibility to experiential science learning. One mentor, when asked what contributed most to her students' learning, shared, '*The link with the community which was really a learning centre because that made a lot of difference*' Students both interviewed and learned from community members, and as the student below illustrates, were then empowered to act as sources of knowledge in the community themselves.

> So, some people were performing the street play, and then…some… who were the advocates, basically after the street play ended, we had to interact with the crowd and ask them questions and…give them like tips on how to save water.

After seeing themselves as successful participants in science, students gained confidence to engage and continue to connect with their community through science.

Student Motivation and Learning in the Future

Students found it engaging to use science-based advocacy to address socio-environmental issues within their community. One student shared what their engagement looked like, '*Then we interviewed people, like what do you do to stop pollution and we did path ahead on a sheet of paper.*' A mentor provided context for the concept students described as the path ahead, '*What is it that the students are going to do to make a difference.*' Overall, we found that students wanted to make an impact in the community while maintaining their interest in science.

In addition, students shared that they planned to engage in science inquiry in the future. This was reflected in the Conference Participant Assessment, by 73.2% of students affirming that participation in the SPIRALS project and conference made them want to act in a more sustainable way. Moreover, 62.6% of students also agreed this participation made them more curious about sustainability. A second mentor provoked discussion about personal decisions students may make as a result of their SPIRALS learning and provided evidence of students reporting changes in their own behaviour.

> What's the one thing, you are going to [do] now after learning that topic, what is a decision you can make in your lifetime… make a resolution. What is the one thing that you are not going to do…[f]or the community? Like in fact … many of the kids, they have actually not burn firecrackers during the festival activity. They said that we will not burn firecrackers.

Because the SPIRALS curriculum encouraged adaptation to best suit the needs and interests of different classrooms, students shared their new understandings with their school and community in different formats. One 7th-grade student commented, '*I enjoyed spreading awareness in my society and in the school by making posters and taking interviews.*' while another student said that they '*prepared a [PowerPoint slide] presentation.*' These various products served as teaching tools during their student sustainability conferences. Anonymous Conference Participation Assessments indicated that 81.2% of students felt knowledgeable about their sustainability presentations. Not only did students see themselves as knowledge sources in their communities, but 63.1% of students also affirmed that they learned about sustainability from other students' presentations.

Overall analysis of the data painted a picture of SPIRALS and community-based science as quite different from the Indian students' usual science experience. By connecting science to their community, the topic became more exciting and interesting. When science was integrated into their community and daily lives, students began to see value in science as a way to understand and improve their community. Moreover, the positive experiences they had engaging with others made students feel capable of contributing to those improvements.

Discussion and Conclusion

Our findings indicate that the SPIRALS curriculum was able to maintain student interest in science at high levels even though the curriculum moved them beyond an exclusive pathway of learning science to get a good job. Students were motivated and interested to learn about science before they engaged with the SPIRALS curriculum and continued to be motivated and interested to learn about science after they engaged with the SPIRALS curriculum. Students in our study reported that SPIRALS allowed them to engage with science collaboratively, and to see it as something valued by others. Given that the SPIRALS curriculum allowed students to conduct scientific inquiry at their own pace and to connect science topics to their everyday lives, students reported that they were excited to do something different and reported a shift to thinking that they can use science to address environmental concerns in their communities.

Along with helping students conduct meaningful scientific inquiry, SPIRALS also aligned with the NCERT suggested guidelines, in that students were able to connect science in the classroom to everyday life or community-based practices. As India moves forward from a history of British colonisation and builds its own emerging identity, schooling will be a key component of social reconstruction for Indian youth. Along with the country's economic growth, environmental problems and social inequities will also need to be addressed and science education will need to play an important part as India creatively overcomes challenges associated with its success.

Schooling will need to do more than train a small number of 'educated' professionals but will need to have the goal of a scientifically literate citizenry able to collaboratively tackle environmental and social problems. Integrating students' expertise about their communities as well as allowing access to community members' expertise highlights the situated, contextualised nature of learning (Hawkins, 2014) and enhances student learning (Bransford, Brown, & Cocking, 2004). Because SPIRALS demonstrated increases in teachers' and students' awareness of and appreciation for local knowledge and its role in their communities' vitality (Sharkey, Olarte, & Ramirez, 2014) it may be a useful model toward achieving these goals.

For science-based community learning to become established, teachers need to ground the science curriculum in the community (Smith & Sobel, 2010). This would radically change teachers' roles in the classroom. Teachers will need to expand their knowledge beyond the science content to include their students' communities. This will require teacher development of partnerships with community assets (Demarest, 2015) and recognition that students are knowledge creators with their own set of abilities and voices (Sobel, 2005). The fact that two of the three Indian teachers interviewed described the use of the SPIRALS curriculum as promoting reflection upon and improvement of their instructional practices is a promising sign that these increased demands may yield professional rewards/benefits.

It is important, however, to realise that in the Indian educational context, teachers must adhere to government-based standards and respond to pressure from parents to teach their children to become white-collar professionals. Schools, with the support of school administrators and government officials, will need to become places where the walls are porous, allowing community members in, to share knowledge and skills, and allowing students out, to explore relevant community strengths and problems.

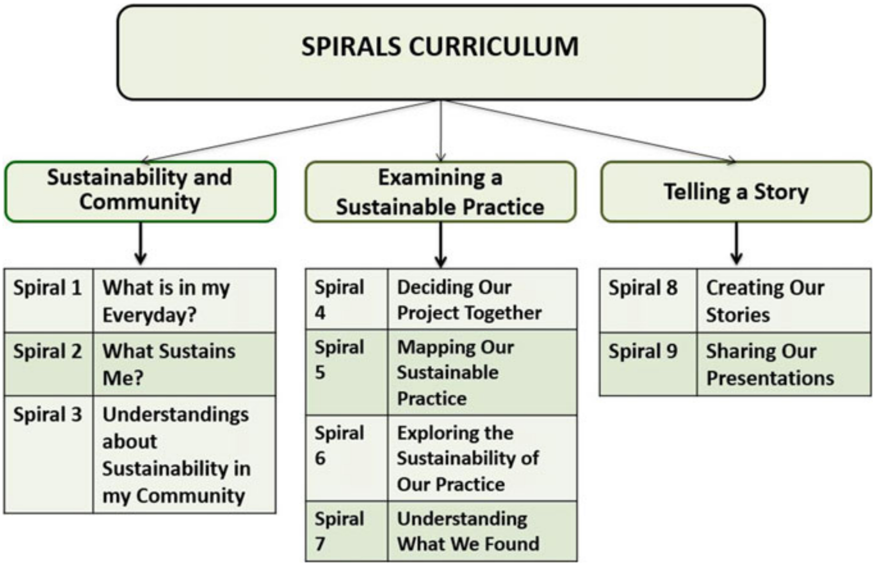
Connecting science taught in the classroom to everyday environmental challenges may sustain student interest in how science can be used to resolve some environmental problems. The SPIRALS curriculum may serve as a model to maintaining interest and motivation in science while guiding students to understand how science is an integral part of their everyday lives in a gradual way. By facilitating classroom-level decision-making, individual classrooms may adapt environmental sustainability lessons to different settings across India, extending to public schools, and other regions across the country.

Appendix

How to Use SPIRALS in the Classroom

The SPIRALS curriculum is composed of nine activity-based lessons or 'spirals' that guide learners on an investigation into the concept of sustainability. The details of how to implement each of these 9 spirals can be found at http://www.spirals.unh.edu/spiralsintro.shtml.

The overall spirals curriculum is structured around three main parts: (1) Sustainability and Community, (2) Examining a sustainable practice, (3) Telling a story.



Through the SPIRALS activities, mentors guide learners in selecting a community practice that the learners are curious about and believe is sustainable. The nine units of the curriculum can be divided into three parts: the first part centres on introducing the concepts of sustainability and community, the second part focuses on learners' researching a sustainable practice, and the third part emphasises telling a story about the sustainable practice the learners researched.

Sustainability and Community

Spirals 1–3 combine an exploration of personal and community sustainability. During these first spiral units, the learners begin to think about what sustainability means and are introduced to the four system conditions of sustainability, which will help guide them in conceptualising the topic. Additionally, groups begin to think about community practices that they might like to investigate in more detail.

Investigation of a Sustainable Practice

During spirals 4–7, groups select a community practice that they feel is sustainable and feasible to study. Groups create maps detailing everything they already know about the practice as a system of interrelated parts. As part of this process, learners reflect on identifying the sources of their knowledge about their selected practice. Next, they create a plan to collect more information about their practice. Once they have collected some data, they carefully re-evaluate the practice by using their definition of sustainability and the four system conditions of sustainability. To help learners appreciate and recall what they have learned, they create a second map of their practice as a system of interrelated parts to display the ways in which they feel their chosen practice is sustainable.

Telling a Story

In spirals 8 and 9, the learners create a digital project and then share what they discovered about their sustainable practice with members of the local community (e.g. school, community centre or library) in the form of a story. In addition, groups are invited to share their stories with family, friends and university scholars at a UNH-sponsored conference specifically for the participants in the SPIRALS program.
The details about each of the spirals can be found listed below:
Spiral 1: What is in My Everyday? (http://www.spirals.unh.edu/spirals1.shtml).

Objectives:

- Learners reflect on their community and identify features that they feel are significant to them.
- Learners create 'My Everyday Maps' to explore the interactions between themselves, the people, places, and things that they feel are important to their everyday experiences.

Spiral 2: What Sustains Me? (http://www.spirals.unh.edu/spirals2.shtml).

Objectives:

- Learners reflect on how their everyday activities keep them going or sustain them.
- Learners reflect on what could be considered a 'need' and what could be considered a 'want' with regard to their life.
- Learners may consider how different features of their everyday help to sustain them in different ways such as emotionally, physically, spiritually, mentally.

Spiral 3: Understandings About Sustainability in My Community (http://www.spirals.unh.edu/spirals3.shtml).

Objectives:

- Learners explore the concept of sustainability.
- Learners identify several practices that they may like to explore further for their group's SPIRALS project.
- Learners use the 'four systems conditions' of sustainability (listed below) to discuss the sustainability of the practices they are considering.
  1. Does the practice support reducing energy use?
  2. Does the practice contribute to lessening man-made waste?
  3. Does the practice reduce destruction of the natural environment?
  4. Is there fairness to all living things (human and non-human)?
- Learners reflect on identifying the sources of their knowledge with regard to the practices they selected through the discussion of traditional ecological knowledge/local knowledge.

Spiral 4: Deciding Our Project Together (http://www.spirals.unh.edu/spirals4.shtml).

Objectives:

- Learners come to a consensus on which sustainable practice is of interest to the group.
- Groups select a sustainable practice that they can explore.

Spiral 5: Mapping our Sustainable Practice (http://www.spirals.unh.edu/spirals5.shtml).

Objectives:

- Learners create a systems map rooted in both traditional ecological knowledge and science of the practice they are interested in exploring.
- Learners should be encouraged to reflect on what and how they know about their topic by demonstrating that there are multiple perspectives to understanding sustainability, including both traditional ecological knowledge and science.
- Learners should discuss and define the SPIRALS core concepts 'system' and 'science'.

Spiral 6: Exploring the Sustainability of Our Practice (http://www.spirals.unh.edu/spirals6.shtml).

Objectives:

- Learners set goals for exploring the sustainability of their practice and establish plans for gathering the necessary information to complete their project.
- Learners identify the tools and resources necessary and available to investigate their chosen practice.

Spiral 7: Understanding What We Found (http://www.spirals.unh.edu/spirals7.shtml).

Objectives:

- Learners organise what they have found about their sustainable practice into categories.
- Learners use what they have learned to begin to form a story or stories about their practice to better understand and share the who, what, where, when, how, and why of their sustainable project.

Spiral 8: Creating Our Stories (http://www.spirals.unh.edu/spirals8.shtml).

Objectives:

- Learners choose a format for their final project presentations. These presentations tell the story about their sustainable practice.
- The story should reflect:
  - Their understanding of sustainability
  - What they have learned about their sustainable practice

Spiral 9: Sharing Our Presentations (http://www.spirals.unh.edu/spirals9.shtml).

Objectives:

- Learners prepare to present their findings to a specific audience (school principal, school board, local conservation commission, etc.).
- The group brainstorm the people and places that might benefit from or enjoy hearing the story of their findings that they composed in Spiral 8.

References

Awasthi, M., & Agarwal, R. (2013). An analysis of various aspects of environmental concern present in NCERT science textbook of class VIII. *Shaikshik Parisamvad, 3*(2), 49–57.

Bang, M., & Vossoughi, S. (2016). Participatory design research and educational justice: Studying learning and relations within social change making. *Cognition and Instruction, 34*(3), 173–193.

Banks, J. (2010). Regulating hate speech online. *International Review of Law, Computers & Technology, 24*(3), 233–239.

Banks, J. A. (2015). *Cultural diversity and education*. New York: Routledge.

Barry, J. (1994). The limits of the shallow and the deep: Green politics, philosophy, and praxis. *Environmental Politics, 3*(3), 369–394.

Blum, A. (1987). Think globally, act locally, plan (also) centrally. *Journal of Environmental Education, 19*(2), 3–8.

Bouillion, L. M., & Gomez, L. M. (2001). Connecting school and community with science learning: Real world problems and school–community partnerships as contextual scaffolds. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 38*(8), 878–898.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2004). *How people learn: Brain, mind, experience and school* (Expanded ed.). Washington, DC: National Academy Press.

Carley, M., & Christie, I. (2017). *Managing sustainable development*. London: Routledge.

Demarest, A. B. (2015). *Place-based curriculum design: Exceeding standards through local investigations*. New York: Routledge.

Dhar, S. (2012). From outsourcing to cloud computing: Evolution of IT services. *Management Research Review, 35*(8), 664–675.

Feinstein, N. W., & Kirchgasler, K. L. (2015). Sustainability in science education? How the Next Generation Science Standards approach sustainability, and why it matters. *Science Education, 99*(1), 121–144.

Field, C. B., Barros, V. R., Dokken, D. J., Mach, K. J., Mastrandrea, M. D., Bilir, T. E. … Girma, B. (2014). *IPCC, 2014: Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects.* Contribution of working group II to the fifth assessment report of the Intergovernmental Panel on Climate Change.

Folke, C., Biggs, R., Norström, A. V., Reyers, B., & Rockström, J. (2016). Social-ecological resilience and biosphere-based sustainability science. *Ecology and Society*, *21*(3), 41. Retrieved from http://www.ecologyandsociety.org/vol21/iss3/art41/.

Gough, A. (2002). Mutualism: A different agenda for environmental and science education. *International Journal of Science Education, 24*(11), 1201–1215.

Guha, R. (2017). India after Gandhi: The history of the world's largest democracy. Pan Macmillan.

Harmon, A. (2017, June 4). Climate science meets a stubborn obstacle: Students. *New York Times.* Retrieved July 5, 2017 from https://www.nytimes.com/2017/06/04/us/education-climate-change-science-class-students.html?_r=1.

Hawkins, M. (2014). Ontologies of place, creative meaning making, and creative education. *Curriculum Inquiry, 44*(1), 90–112.

Hestness, E., McDonald, R. C., Breslyn, W., McGinnis, J. R., & Mouza, C. (2014). Science teacher professional development in climate change education informed by the Next Generation Science Standards. *Journal of Geoscience Education, 62*(3), 319–329.

Intergovernmental Panel on Climate Change. (2013). *Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change.*

Iyer, R. B. (2015). Blending East and West for holistic education. *Educational Research and Reviews, 10*(3), 244.

Jackson, M. G. (2002). Effective environmental education needs 'new' science. *Indian Educational Review, 37*(2), 22–38.

Jackson, M. G. (2003). From practice to policy in environmental education. *Southern African Journal of Environmental Education, 20,* 97–110.

Kern, A. L., Honwad, S., & McLain, E. (2017). A Culturally relevant teacher professional development for teaching climate change to Native American students. *Journal of Education and Training Studies, 5*(10), 1–17.

Kingdon, G. G. (2017). The private schooling phenomenon in India: A review. *Centre for the Study of African Economies.* Retrieved from https://www.csae.ox.ac.uk/materials/papers/csae-wps-2017-04.pdf.

Kohtala, C. (2015). Addressing sustainability in research on distributed production: An integrated literature review. *Journal of Cleaner Production, 106,* 654–668.

Lotz-Sisitka, H., Wals, A. E., Kronlid, D., & McGarry, D. (2015). Transformative, transgressive social learning: Rethinking higher education pedagogy in times of systemic global dysfunction. *Current Opinion in Environmental Sustainability, 16,* 73–80.

Lozano, R. (2008). Envisioning sustainability three-dimensionally. *Journal of Cleaner Production, 16*(17), 1838–1846.

Mochizuki, Y., & Bryan, A. (2015). Climate change education in the context of education for sustainable development: Rationale and principles. *Journal of Education for Sustainable Development, 9*(1), 4–26.

Muttarak, R., & Lutz, W. (2014). Is education a key to reducing vulnerability to natural disasters and hence unavoidable climate change? *Ecology and Society*, *19*(1), 42. Retrieved from http://dx.doi.org/10.5751/ES-06476-190142.

NCAER. (2005). *india science report*. New Delhi: National Council of Applied Economic Research.

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

Pande, A. (2001). Environmental education in rural central Himalayan schools. *The Journal of Environmental Education, 32*(3), 47–53.

Pande, L. (2002). Our Land, Our Life: An innovative approach to environmental education in the central Himalayas. *Education and Sustainability: Responding to the global challenge*. Gland, Switzerland and Cambridge, UK: International Union for the Conservation of Nature, 65–73.

Penuel, W. R., Harris, C. J., & DeBarger, A. H. (2015). Implementing the next generation science standards. *Phi Delta Kappan, 96*(6), 45–49.

Ramadoss, A., & Poyyamoli, G. (2011). Biodiversity conservation through environmental education for sustainable development-a case study from puducherry, India. *International Electronic Journal of Environmental Education, 1*(2).

Ramasami, T. (2009). India's rocky road to scientific success. Interview by Joerg Heber. *Nature Materials, 8*(5), 362.

Resnick, M., & Wilensky, U. (1998). Diving into complexity: Developing probabilistic decentralized thinking through role-playing activities. *The Journal of the Learning Sciences, 7*(2), 153–172.

Schultz, K., Kumar H & Gantleman J. (2017, November 8). In India air so dirty your head hurts. *The New York Times*. Retrieved from https://www.nytimes.com/2017/11/08/world/asia/india-air-pollution.html.

Sharkey, J., Olarte, A. C., & Ramirez, L. M. (2014). Developing a deeper understanding of community-based pedagogies with teachers: Learning with and from teachers in Colombia. *Journal of Teacher Education, 67*(4), 306–319.

Siddiqui, T. Z., & Khan, A. (2015). Environment education: An Indian perspective. *Research Journal of Chemical Sciences, 5*(1), 1–6.

Smith, G., & Sobel, D. (2010). *Place-and community-based education in schools*. New York: Routledge.

Sobel, D. (2005). *Place-based education: Connecting classrooms and communities*. Barrington, MA: Orion.

Sonowal, C. J. (2008). Indian tribes and issue of social inclusion and exclusion. *Studies of Tribes and Tribals, 6*(2), 123–134.

Stevenson, R. B., Brody, M., Dillon, J., & Wals, A. E. (2013). *International handbook of research on environmental education*. Routledge.

Thomas, B., & Watters, J. J. (2015). Perspectives on Australian, Indian and Malaysian approaches to STEM education. *International Journal of Educational Development, 45*, 42–53.

Wildschut, D. (2017). The need for citizen science in the transition to a sustainable peer-to-peer-society. *Futures, 91*, 46–52.

Talent Identification and Talent Nurture: The Indian Story

Aniket Sule

Abstract The phrase 'talent identification' is much maligned in India. In a country with a large student population and limited opportunities for mentoring, there is always a lot of demand for participation in any talent nurture programme. This aspiration of parents and students is also exploited by commercial entities peddling substandard alternatives to talent nurture. All these efforts work within an assumption that talent is an innate characteristic, which just needs timely identification and then systematic mentoring. On the other hand, defenders of social justice reject the very concept of talent as an elitist, exclusionary framework. We will take a middle view that, although talent is not an innate characteristic, early nurture of an individual imparts a set of skills, which are later mistaken for talent. This chapter tries to present a short overview of talent identification and talent nurture efforts over the last 50 years. It will give the reader a fair idea about types of programmes which have already populated the landscape, their strong points and shortcomings.

Introduction: What Is Talent?

Most laypeople or even most scientists working in natural sciences would say this is a trivial query with an obvious answer. They would tend to believe that one intuitively understands the word 'talent' and it is easy to spot a 'genius' or a 'talented person' or a 'gifted individual'. Seasoned teachers spot 'talented persons' through their classroom interactions. Policy makers rely on standardised IQ tests or aptitude tests. Sports and Music coaches claim to spot talent through careful observation and analysis of their wards. Prima facie evidence suggests that there is merit in such identification of talent. The history of science or music or sport or of any field, for that matter, will tend to include countless stories of individual 'geniuses' who single-handedly changed those fields. When you think of the word 'genius' it is difficult not to associate it immediately with names like Einstein, Newton, Gauss, Emmy Noether or Srinivas Ramanujam. Sportspersons like Pele (Soccer) or Muhammad Ali (Boxing)

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or Bradman (Cricket) spring to mind who exhibited skills superior to their peers by a significant margin. Examples such as these reinforce the common perception that some individuals have some kind of innate proficiency in certain disciplines and one of the qualities of a good educator is an ability to recognise and nurture such a talent.

This view also resonates with early twentieth century belief about innate intelligence. Identification of talented individuals was primary focus of many institutes of learning. At the same time, it was also believed that geniuses suffer from stunted growth in other spheres of life such as social sphere, physical health and proficiency in fields other than their chosen one. In fact, Lewis Terman's great longitudinal study of a large sample of genius children (1922, 1923) started with testing validity of this belief about stunted growth of genius children. In later volumes, he studied other aspects of their development and career progression. Terman's study has itself led to innumerable follow-up articles, studies and meta-analyses. Early followers of Terman's study preferred to subscribe to the core concept of innate proficiency, however, later analyses (Gladwell, 2008; Shurkin, 1992) also showed shortcomings of this study in terms of flawed scientific methodology and questionable premise of innate proficiency.

Educationists tend to shy away from the word talent. Pearson's (1931) analysis, published as volume 3 of Terman's study, points out that results of an IQ test conducted at an early age are not reliable indicators of talent. There are multiple commentaries (Gladwell, 2008; Piirto, 1994; Shenk, 2010) pointing out that genius is not an innate ability. As Ericsson, Krampe, and Tesch-Römer (1993) point out, being talented at something is more a matter of practice than any genetic traits. One can even take the pendulum to other extreme and argue that most children (barring those with significant cognitive disabilities) are born with more or less similar innate abilities, and the type of nurture in the early years of development can help them acquire proficiency in certain skills which are later mistaken for innate talent. A child born in a multilingual environment may pick up as many as 5–6 languages even before starting school if the parents encourage him/her to explore all people in his/her proximity. Exposure to daily tasks involving logical thinking may lead to mathematics proficiency at an early age or exposure to working on precision hands-on tasks like sewing may lead to better hand-eye coordination which will benefit batters in baseball or cricket. In many cases, this correlation may not be apparent as nurture at an early age is not a conscious choice. However, several studies, including those in Indian settings conducted at HBCSE, have shown that the gap between 'high performing' and 'average' individuals can be significantly reduced by changing the learning environment even at a later stage. The households where education is valued are likely to provide much better conscious or unconscious nurture through choice of toys, exposure to books etc. On the other hand low-income households or households with low parental education may not make the same choices. Thus, the children from these families would be at a natural disadvantage. One cannot claim that 'talented individuals' can never come from disadvantaged families, however, but if we study such cases, for most of these individuals, their families made a conscious effort to support them despite all the hardships.

In this chapter, we will use the word ‘talent’ as an acknowledgement of high scholastic aptitude. One cannot deny the fact that, at the high school level, there are students who exhibit much higher scholastic proficiency as compared to their peers and we will call them talented individuals. As discussed above, this aptitude may not be innate and hence our categorisation may be demeaning to other individuals who did not get the same opportunities. However, we will use it, nonetheless, as a concise nomenclature for this group of individuals.

Talented individuals can further be categorised into two subgroups. The first subgroup would be, what one calls, an ‘all rounder’ in sporting parlance: someone who shows proficiency in multiple fields and skills. In the educational context, a student may show special competence in multiple scholastic subjects or show additional talents in non-scholastic areas. In fact, there are examples of multiple scientists who were talented musicians or scientists who could have been equally informed in diverse areas like history or arts. Sir C. V. Raman combined his expertise in Physics and Tabla, an Indian percussion instrument, and wrote scholarly articles on the vibrational modes of the diaphragm of a Tabla. The other group of talented individuals are specialists who excel in one field but do not show any interest in exploring other fields of knowledge. An often cited example of this behaviour is Srinivas Ramanujan, who was probably one of the most gifted mathematicians of the past century but had no visible interest in anything except mathematics.

Various mechanisms have been devised to nurture these talented individuals. We will review some of the talent identification and nurture programmes during the course of this chapter. While mainstream thinking supports the idea that talented individuals require special guidance and support to hone their skills, there is an alternate school of thought which believes that the role of structured nurture programmes is not as crucial to talent development as conventionally thought. This group believes that, if these talented individuals are given access to resources, they can make optimal use of these resources to develop themselves as per their individual needs, preferences and pace. We will also discuss home-schooling in the Indian context as an example of this philosophy.

Identification of Talent

Let us begin with various schemes for identification of talent in India. Although talent identification can be in any subject area, most of the prestigious schemes run by various government authorities focus on science subjects. This bias stems from the fact that, after common basic schooling, an overwhelming majority of high performing students opt for careers in STEM. Even within STEM, most students prefer undergraduate degrees in engineering or medicine, as these disciplines are seen as ones leading to a high paying career. Thus, the government schemes aim to stem this flow of high performers to engineering or medicine and lure at least a few of them towards theoretical sciences. We will discuss the history of these schemes, followed by a short comparison.

National Talent Search Examination

One can view the National Science Talent Search Scheme (NSTSS) as the first national-level programme aimed at identifying and rewarding high performing individuals in the final year of secondary school (formerly class 11, presently class 10). This is an examination conducted by the National Council for Education, Research and Training (NCERT). The examination was first conducted in the national capital region of Delhi in 1963, and subsequently it expanded to encompass the national level from 1964. In that year, 350 students were selected nationally for the award of a scholarship. In its present form, the scheme is known as the National Talent Search Examination (NTSE). The number of aspirants has grown to more than a million students every year. The number of scholarships has risen to 1000 every year with 225 of them earmarked for affirmative action towards disadvantaged communities. To keep the number of students competing in the NTSE restricted, a two-tier system of examination has evolved. Each of the states is advised to conduct their own state-level examination with similar format and each state is allotted a fixed quota of students to recommend for the national level test. The numbers for each state are in proportion to the student population in those states and the total number of students competing in the national test is roughly 4 times the number of scholarships available.

The philosophy of selection has also undergone changes over the course of the last 50 years. Initially, the written examination consisted of a scholastic aptitude test (SAT) for science and mathematics and an essay on a scientific topic. The aspirants were also required to submit a project report at the time of the written examination. Approximately the top half of the students competing for the national test were invited for an interview and the final merit list was prepared based on the combined score of all four components. Within a few years, policymakers realised that a narrow focus on science and mathematics was not the way forward. In addition, inherent error margins in assessment of subjective components, like essays and project reports, made them less desirable options. Thus, the written test was reformed to include two components of equal weight: A mental aptitude test (MAT) and SAT. Both tests were multiple choice tests with 100 questions to be solved in 90 min in each test. For the SAT, students had a choice of 8 subject areas (25 questions each) namely physics, chemistry, biology, mathematics, history, civics, geography and economics, and each student could attempt 4 subject areas of his/her choice. In 1995, the SAT section was reformed again to eliminate the choice for the students. Each student was required to attempt same 40 questions on science, 40 on social science and 20 on mathematics. Between 2006 and 2012, NTSE examinations were conducted for students of class 8 instead of class 10, but the move received negative feedback and just after 6 years, the examination came back to class 10.

The original scheme envisaged talent identification as well as nurture of selected students. The selected students would receive scholarship for their entire college education as well as being invited for summer camps to nurture their interest in science. A lot of senior academicians of that generation immensely benefited from this scheme, both in terms of financial support as well as exposure to modern research. Later, as the number of scholarships increased and the scope of the examination included both natural and social sciences, this nurture dimension of the programme was discontinued. In recent years, NCERT has been trying to bring the nurture dimension back into the scheme in some form.

KVPY, INSPIRE and NIF Awards

The Government of India introduced Kishore Vaigyanik Protsahan Yojana (KVPY), i.e. young scientists' encouragement scheme, about 15 years ago. This scheme also primarily targets secondary (class 10) and higher-secondary (class 12) students. The students are selected through an objective response (mostly multiple choice) examination and interviews and they are offered scholarships for their entire college education, provided they opt for a pure science undergraduate and/or postgraduate course. An offshoot of this scheme allows a few students pursuing engineering/medicine to also participate in pure science research work.

The Innovation in Science Pursuit for Inspired Research (INSPIRE) scheme was initiated by the Department of Science and Technology 10 years ago as a large scale talent identification and award programme. This scheme works differently for different age groups. At middle school level, the scheme aims to bestow a one-time nominal cash award to an enormously large number of students (the target number is one student from every school in India) and students are required to utilise this award to realise a small project of their choice. There is no centralised selection process and it wholly depends on nominations from schools. At high school level, the students in the top 1 percentile from each state are invited to participate in week-long expository camps under this scheme. Again the numbers are too large for any centralised selection and selection is merely based on nomination by the schools. At the undergraduate level, every year the scheme aims to award scholarships to 10,000 students pursuing degrees in pure science. The selection of these students is based on their performance in their high-school board examination and the selected admission tests of various undergraduate programmes. The scheme also includes a post-Ph.D. branch, where promising young post-doctoral fellows are awarded a 5-year duration "INSPIRE faculty fellowship" which includes research and travel grants along with salaries.

The National Innovation Foundation (NIF), established in 2000, has approached talent identification from another side. The foundation identifies and rewards grass-root innovators. It helps them secure Intellectual Property Rights (IPR) for their innovations and also provides support to translate these innovations into mass scale products. Although NIF recognises innovators from all walks of life and of all ages, there is also a specific scheme to encourage young students to come up with innovative ideas and the best ideas are selected through a cascading model. This system is also replicated in other science fairs organised across the country under the aegis of different organisations, state education boards, NCERT and private companies like Intel and Google.

Undergraduate Admission Tests: JEE and Others

In India, it is common to conduct admission tests after high school to decide which students can get admissions to the most coveted colleges. It is assumed that it is the most fair and objective way of deciding which students are worthy of admission. This is partly due to the fact that educational standards of different school boards vary vastly and partly because there is little faith in fairness and accuracy of grades awarded based on school board examinations. The purpose of such examinations is not talent identification, but the aspirant's performance in these examinations is taken as a proof of his/her talent. Thus, these examinations are also of interest. The prestigious Indian Institutes of Technology (IITs) system has a 60-year-old examination called the Joint Entrance Examination (JEE). Like NTSE, the JEE examination also underwent several transformations. Firstly, the test on language skills was discontinued, then the subjective nature of questions was changed to multiple choice questions. Now, this examination is taken by more than a million students every year and there are many who believe that their career entirely hinges on this one examination.

Similarly, the National Eligibility cum Entrance Test (NEET) has been established in the last decade as the common all-India entrance examination for medical and paramedical courses. Several government institutes, as well as private institutes, have their own entrance examinations for admission to undergraduate courses. Similarly, most states started their own state-wide JEEs for admission to engineering and medical courses in those states. The supreme court of India ruled in the T. M. Pai Foundation vs. State of Karnataka case (2002) that each private university will be within their right to conduct their own entrance examination. The following decade saw a proliferation of so many distinct examinations that it was common for a high-school graduating student to take part in more than 25 entrance examinations in a two-month summer break. The last five years have seen a consolidation of these examinations to a much smaller number due to pressure by the government to reduce stress on students.

The Coaching Route to Success

The high stakes entrance examinations at the end of high school have led to the establishment of private coaching centres which train students to succeed in these examinations. The coaching centres first started appearing in the 1980s and became all pervasive and powerful over the following two decades. Presently, the entire high school level education system in several big cities has been virtually hijacked by the coaching centres. The students in these cities enrol in schools owned by these coaching centres and, for all practical purposes, their faces are never seen at school. Their day starts and ends in the coaching centre. The subjects which are not included in JEE or NEET, like languages or even the experimental skills in sciences, are largely ignored by these coaching centres. Many students from other towns across India join coaching centres in Kota or Hyderabad and live in hostels which have sprung up in large numbers in these cities. The gruelling routine in these coaching centres is becoming a mental health hazard. The coaching centre hubs like Kota (a smaller city in the Indian state of Rajasthan) show significantly higher rates of student suicides as compared to other cities. The students coming out of these coaching centres show higher burnout rates than the rest of the population. These coaching centres are the epitome of all that went wrong in the maddening race to identify talented students.

Olympiads

Academic Olympiads for high school students started in Eastern Europe more than 50 years ago. India joined the International Mathematical Olympiad in 1989 and entered the Olympiads for Physics, Chemistry, Biology and Astronomy in the late 1990s. The Indian Olympiad programme is administered by the Homi Bhabha Centre for Science Education (HBCSE-TIFR) in Mumbai. The Olympiads are aimed at final year high school students, with the exception of the International Junior Science Olympiad, which is only for students who are less than 15 years of age. About 200,000 students cumulatively participate in various Indian Olympiads. In terms of international participation, the Indian Olympiad programme has been a major success, with more than 95% of students returning from International Olympiads with a medal and more than 30% of students bagging the most coveted gold medals. These examinations are more challenging than regular school examinations. They aim to test conceptual knowledge and there is also a heavy emphasis on experimental skills, which is sorely missing from all other examinations for the same age group.

Following the example of India, other South Asian countries like Nepal, Sri Lanka, Bangladesh and Pakistan have also initiated participation in International Olympiads. However, so far, they have not achieved similar success to India in the International Olympiads.

The Indian Olympiad programme goes much beyond mere talent identification. The Olympiads in every subject include a residential camp of 35–50 students during the summer period. In these camps, students interact with leading researchers in that subject area and also get their first real exposure to research work, experimental investigations and problem-solving. It is hoped that they can, therefore, make informed choices about their careers.

Private Examinations

In modern India, where quality of education is equated with quality of school infrastructure and the quality of private schools is judged by the amount of fees charged by the school, it is no wonder that private agencies have entered the market of talent identification in a big way. There are a number of examinations which target rich schools and claim to aid in talent identification through a multiple choice test. In reality, most of these examinations charge a high participation fee and strive to please almost every ‘customer’ by offering some kind of recognition certificate. Some of these examinations include extravagant awards like a trip abroad, which play on the aspirations of the upwardly mobile Indian middle class. One must acknowledge that there are unpretentious, honest voluntary bodies who conduct a number of good talent identification examinations at the regional level. However, they have taken a backseat with the onslaught of big commercial players.

Undergraduate Level Talent Identification

If we look at the undergraduate education sector, there are very few examinations/competitions aimed at talent identification. The National Board of Higher Mathematics (NBHM) runs a competition titled Madhava Mathematics Competition for undergraduate (UG) students with mathematics as one of the subjects. Similarly, the Indian Association of Physics Teachers (IAPT) has been running the National Graduate Physics Examination (NGPE) for nearly 30 years for Physics students. Various colleges and Institutes organise technology festivals every year where there are numerous competitions for UG students. However, these competitions do not have a similar reach to the competitions at high school level.

Advantages and Shortcomings

Most of the talent identification programmes use multiple choice examinations as a first filter. Multiple choice or other objective type questions provide an advantage in that they can be machine graded and there is little scope for subjectivity, as introduced by a human grader reading descriptive answers. Students’ language skills, be it in terms of writing an answer or expressing it orally, don’t play a significant role in standardised objective tests. They can be administered in a uniform manner at many locations. In the modern context, they can also be administered on computer terminals at designated examination centres or even over the internet. As the candidate has to only click on an option, the typing skills (or lack thereof) of the candidate do not affect his/her performance. In India, where competition for these examinations is intense and every examination faces legal challenges by unsuccessful candidates, these kinds of tests are considered transparent and legally defensible.

However, these advantages are also the shortcomings of these examinations. The ‘right or wrong’ kind of binary philosophy of these tests doesn’t take account of why any candidate recorded an incorrect response. All wrong responses are penalised equally. You may make a critical conceptual mistake in the first step of your solution or make a trivial calculation error in the very last step, what matters is you did not reach the ‘right’ answer. So you will be deemed ‘equally wrong’. In fact, most of these tests include negative marking to prevent random guessing. Giving a wrong answer will earn you a penalty but not attempting a question doesn’t yield any penalty. In turn, if you know how to solve a question but make a trivial mistake somewhere, you would be worse off as compared to someone who has no clue about the question. Coaching centres are in favour of these kind of examinations, as it is easier to train aspiring candidates to perform well in these kinds of tests. By their very nature, multiple choice questions represent a highly restrictive format to designing good probing questions. One can train candidates to reverse the process, i.e. simply check if the given options give a satisfactory answer to the question. In most cases, the paper setters are not careful enough to put meaningful distractors and it is easy to rule out 3 of the 4 options as unrealistic/meaningless. This leaves only one option as a possible answer. One doesn’t really have to know how to solve the question to reach that answer and gain points. Worse, one can create a compendium of all possible questions and force the aspiring candidates to memorise these. Thus, any question in any examination could be answered by recalling appropriate prototypes from memory. For those unfamiliar with the Indian education scenario, this may appear to be a fairy tale, as any such compendium will be intimidatingly huge and memorising it would be considered beyond the cognitive abilities of any 17 years old. However, several coaching centres are known to use this approach through a multiple-year gruelling routine, forced on aspiring candidates.

With such distortions, one is left wondering if the talent identification examinations are really achieving their purpose. In the suite of Olympiads, there are some, like the Mathematics Olympiad and the Astronomy Olympiad, where the ‘syllabus’ of the Olympiads has no relation to the regular high school syllabus. Thus, there are not many coaching factories training students for these examinations. As a result, these Olympiads are far more successful in unearthing hidden gems as compared to Olympiads based on school syllabii. In these Olympiads, we many times meet students who are truly talented, but don’t shine in run of the mill talent identification examinations for various reasons. Some hate the cramming part of the examination ‘training’ and lose interest, some live in remote areas and don’t have access to coaching factories and some stay away from coaching factories due to financial constraints. On the other hand, we also keep meeting some talented students on the verge of burnout as they are unable to cope with the pressure of coaching.

Social Justice and Talent Identification

As seen above, most of the typical Indian talent identification examinations require extensive training or coaching for the candidates. This translates into the fact that success in such examinations will depend on access to information about these examinations, physical access to training resources and financial resources to support such training or coaching. Access to information is usually restricted to a small percentage of mostly urban schools. Physical access is not just availability of training resources in your physical proximity but also social acceptance of a student's need for utilising such resources. It is speculated that a large percentage of Indian parents are less inclined to invest in training programmes for female children as compared to a male child. Similarly, a family which places importance on education is more likely to support the coaching aspirations of its children. As a result, even in urban centres, females and socially underprivileged groups have less access to training resources compared to boys from well-educated, higher caste, well-endowed families. Financial access is also a significant issue in India, where fees of any top-level coaching institute are typically more than the annual income of 80% of the Indian workforce.

Most government run talent identification competitions and entrance examinations take cognizance of this reality. Many examinations, including JEE, KVPY and NTSE, include affirmative action riders for socially underprivileged castes. Some of the states include affirmative action clauses for female students in their UG admission process. However, there is no unanimity regarding extending affirmative action benefits to females in national level examinations.

Talent Nurture

Although most efforts in this area focus on talent identification and rewards, there are a few programmes which focus on nurturing talent and polishing up skills. Some of these programmes have their own talent identification components, while some of the programmes shun the idea of talent identification altogether.

Expository Camps

NTSE and KVPY examinations organise short duration nurture camps for winners in the respective competitions. The camps include lectures on cutting-edge science, some laboratory sessions and visits to research laboratories. The INSPIRE programme also includes provision for similar exposure camps at high school level. These camps serve the purpose of giving a first taste of modern science to young students. These camps are organised in several places simultaneously in a completely autonomous manner. However, the decentralised nature of these camps also means that the academic programme varies vastly from one location to another. The lack of a common template affects the quality of camps held in smaller places.

Another model of nurture camps is followed by the Astronomy Olympiad programme. Past participants of the Astronomy Olympiad programme are invited to join a two-week nurture programme every year in December at different astronomical research institutes. These students do group projects using real astronomical data and get first-hand exposure to research level data analysis.

MTTS

The Mathematics Training and Talent Search (MTTS) is arguably the most successful talent nurture programme in the Indian education system. It was initiated in 1992 by Prof. S. Kumarasan (then working in Mumbai University) under the aegis of NBHM. This programme is for UG and postgraduate students and each participant can attend it for a maximum of three years. The programme involves a one-month residential camp where students get exposure to systematic mathematical arguments and get a new insight into problem-solving. There is no research component. In the last 25 years, the programme has created a vast network of past participants. Most of the younger mathematics faculty in all Indian institutes have participated in MTTS at least once and many of them now get involved in the MTTS programme to train the new generation of mathematics students. Many short courses taught under the MTTS programme have led to the creation of resource materials and in the last few years, week-long mini-MTTS programmes have been started to accommodate a growing demand from the student community.

VSRP and Other Similar Fellowships

Most Indian research institutes offer a Vacation Student Research Programme (VSRP) for pre-final year masters students. Similarly, science academies in India offer summer research fellowships for the same group of students. For all of these programmes, the selected students spend about 6–8 weeks in the respective research institute. They attend a number of lectures but also do a small research project with a mentor in that institute. These programmes do serve as good publicity for the research institute among prospective students. Up until the mid-2000s, several institutes also offered direct admission to graduate schools for the best VSRP students. However, that practice has now been discontinued. Similar summer fellowships are also offered by science academies in India. Recipients of these fellowships work with fellows of these academies in their respective institute for a duration similar to the VSRP. Further, several new scholarship schemes like KVPY and INSPIRE include a mandatory project work component for all recipients of these scholarships. Students at premier science institutes (IISERs, NISER, IISc, UM-DAE CEBS, CMI, IIST etc.) are also expected to take up research projects in each summer vacation.

NIUS

In 2003, HBCSE introduced the idea of proto-research projects for early UG students through a new programme called the National Initiative in Undergraduate Science (NIUS). This programme differed from VSRP and other similar fellowships in several ways. It was the first programme targeting early UG students instead of masters students. It is an extended nurture programme where the selected students remain part of the programme for a period of 2 years. In the beginning, they undergo some basic training at HBCSE after completing one year of their UG programme. A fraction of these students are assigned proto-research projects with researchers from different academic institutes. These students interact with their assigned mentors over the following two years and visit their institutes during each vacation period to work on the research project. This gives students adequate time to grasp the research area in a more comprehensive manner and allows them to make a meaningful contribution, which is not possible in a single 8-week window. After the foundation of premier science institutions, the NIUS was reoriented to specifically target students from non-premier academic institutes. The proof of this concept is demonstrated through a number of research publications by UG students, completed through this project and published in leading research journals. The project presently runs in the subject areas of Astronomy, Biology, Chemistry and Physics.

Home-Schooling

In India, home-schooling is still in a nascent stage and seen pre-dominantly in metro cities. Home-schooling in India stems from totally different considerations compared to some of the home-schooling experiments in the USA. Well-educated parents of high performing children opt for home-schooling in order to focus on extra nurture of the child's perceived talent. Parents of home-schooled children have formed associations like *Swashikshan* (meaning self-education http://homeschoolers.in/), where they exchange tips and conduct workshops on academic as well as legal aspects of home-schooling. In some cases, the home-schooled students continue with a traditional curriculum without formally enrolling in a school and it is argued that home-schoolers have made this choice as the quality of teaching-learning in the schools is 'unsatisfactory'. Thus, it is in the interest of talented individuals to opt out of the school and learn at an accelerated pace. In other cases, home-schooled students shun the standard curriculum completely and only focus on a few subjects in which they would like to excel. In such cases, the primary argument is that the school does not give enough opportunities to high performing children to truly excel in their chosen area and other subjects in standardised curriculum are ‘just a distraction’.

The home-schooling experiments in India will require some more time before one can evaluate their success. The higher education institutions in the country also have to evolve their admission processes to even consider applications from home-schooled students, which would not fit the checkboxes of scores in standardised examinations etc. The experiment is viewed sceptically by academicians, as in several high profile cases, parents pushed their children to undergo accelerated learning and to complete post-graduation by the age of 15. However, such trailblazers did not live up to the hype created around them. Home-schooling is also facing ethical and legal questions from other quarters. India passed a ‘Right to Education’ (RTE) act in 2009, which makes education, up until the age of 14, a fundamental right of every child. Some non-governmental organisations working in the area of child welfare argue that parents wilfully not sending their children to a school amounts to infringement of this fundamental right. The RTE act also specifies norms for the minimum quality of education to be imparted in all places of learning and mandates the government authorities to ensure that these norms for quality are met. Since the same cannot be verified in the case of home-schoolers, the quality of education received by them can be deemed to be compromised. Further, it is argued that the standard curriculum has been developed for young children to ensure their holistic development. Home-schoolers focussing on only selected subjects are denied this opportunity. On ethical grounds, it can also be claimed that by turning a blind eye to these home-schooling experiments, the government is actively discriminating between its citizens, where elite, urban, well-educated parents are allowed to opt their children out of school, but the same option is not available to a lesser educated or poor work-smith or a farmer.

Rethinking Talent Nurture: Vigyan Pratibha

With this myriad of schemes for talent identification and nurture, one sometimes wonders if the very spirit of providing the right sort of encouragement to all those with potential to excel in science and mathematics is getting lost. As every talent identification/nurture programme is oversubscribed several times over, there is immense competition to gain entry. By its very nature, the large-scale competitive examinations favour a small resource-rich fraction of the student population. Here the term resource-rich encompasses several discriminating factors. Being financially better off is the obvious discriminating factor, but one can be resource-rich or resource-deprived based on social status, education level of parents, valorisation of education in the family, access to study materials, access to technology, access to better teachers, access to exposure to the world around them or even gender. In a country like India, there is still a disparity in the amount of resources made available for education of a female child compared to that of a male child. As the gatekeeping examinations are biased, obviously, the access to these prestigious programmes can be restrictive to many students.

In order to reach out to a wider student population, one would need a programme which does not involve any selection process. Every student who wishes to participate in this programme should be able to do so. Designing such a programme on a national scale without compromising quality is the first big challenge. The second logistical challenge is to create a pool of mentors and resource persons who can scaffold the programme at a grassroots level and there are organisational challenges to providing the extra mentoring which needs to be imparted. One possible solution to overcome both these challenges would be to build a national network of capable school teachers who will not only implement the programme in their respective schools but also provide peer support to each other to gain additional expertise in mentoring talented students.

In July 2017, HBCSE launched an ambitious new programme under the title '*Vigyan Pratibha*' (meaning science talent). This programme is aimed at students from classes 8, 9 and 10 from the central government-owned schools. Under this programme, HBCSE will design learning units which go beyond the standardised curriculum and challenge students to go deeper. Many of the units will involve some hands-on component and employ an enquiry-based learning strategy, which is presently missing from the standard curriculum. Acknowledging the fact that creating specialised resource persons only for this kind of large scale programme is neither desired nor practical, the deployment of these learning units in schools critically hinges on the willingness of teachers themselves. The programme will offer training to teachers who wish to reorient themselves to adopt a different style of teaching and offer incentives to school science clubs which are active in the programme. However, on purpose, there is no component in the programme which focusses on evaluation of either teachers or students. We believe that avoiding evaluation would allow students to focus on the learning aspects of the units.

The learning units already developed under this programme are showing potential for rich learning without accelerated learning of advanced topics. For example, textbooks already include activities on Archimedes principle and suggest hands-on activities to measure the volume of a rock by dipping it in water. The corresponding Vigyan Pratibha unit goes a step further. It tries to connect this concept to Aesop's fable of the thirsty crow and prods students to recreate the scenario with different amounts of water. Through trial and error, they realise that the water would occupy the spaces between the balls being put in the water and no packing can be perfect. The purpose of these units is not just to teach a scientific concept but also to introduce the skills of systematic investigation, scientific reasoning, etc. It is hoped that this sustained in-school talent nurture programme will create a new model which can be adopted by other programmes.

Summary

The Indian talent nurture landscape is rich in diversity. The selection process for Indian programmes differs significantly from the American and European talent nurture programmes. The programmes in western countries are also oversubscribed but the subscription ratio is not too high. Hence, it is still possible to examine each application in detail from all aspects and make an informed selection. However, with such a large student pool and limited opportunities, the oversubscription ratio for every programme in India is very high and hence impersonal selection processes take precedence. These selection processes give unfair advantage to urban, elite students and hence are detrimental to the larger goal of encouraging talent from all strata of society. To achieve that goal, instead of ‘pulling-out’ a select few students and trying to nurture them, the talent nurture programmes should ‘drop-in’ where the students already are, i.e. in each and every school. Teachers would have to play an important role in this ‘drop-in’ model as external educators cannot reach every nook and corner of the country.

References

Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100*(3), 363.

Gladwell, M. (2008). The trouble with geniuses, Part 1 “Knowledge of a boys’s IQ is of little help if you are faced with a formful of clever boys.” *Outliers: The story of success* (pp. 69–90). New York: Little, Brown & Company.

Pearson, K. (1931). Genetic studies of genius Vol. 3: The promise of youth: Follow-up studies of a thousand gifted children. *Nature, 127,* 772–774.

Piirto, J. (1994). *Talented children and adults: Their development and education*. Columbus, OH: Merrill/Prentice-Hall.

Shenk, D. (2010). *The genius in all of us: New Insights into genetics, talent and IQ*. New York: Anchor Books.

Shurkin, J. N. (1992). *Tracking the IQ elite: Terman’s kids: The groundbreaking study of how the gifted grow up*. New York: Little, Brown & Company.

T. M. Pai Foundation vs. State of Karnataka. (2002). https://righttoeducation.in/sites/default/files/W.P.%20(C)%20No.%20350%20of%201993.PDF.

Terman, L. M. (1922). A new approach to the study of genius. *Psychological Review, 29*(4), 310.

Terman, L. M. (1923). *Mental and physical traits of a thousand gifted children* (Vol. 1). Stanford University Press.

Vigyan Pratibha. http://vp.hbcse.tifr.res.in.

Indigenous Knowledge, Technology, and Innovation

Learning to Teach and Teaching to Learn STEM Through a Makerspace Approach

Rachel Sarah Sheffield, Jose J. Kurisunkal and Rekha Koul

Abstract This chapter outlines the implementation of a STEMinist Makerspace Project with a group of female primary pre-service teachers in India. The STEMinist project had previously been enacted in Australia, Indonesia and Malaysia, and targeted female pre-service teachers focusing on building their science, technology and mathematical knowledge and engineering process skills, empowering them to become more confident and competent STEM educators. Using a *Makerspace Approach* pre-service teachers participated in a series of activities: first, as 'students' in a Makerspace creating their own artefact supported through a scaffolded approach by their educators; reflecting on their experiences; then taking their artefact and materials to scaffold and support primary school students to create the own artefacts that they were able to take home. It was evident that the pre-service teachers focused on the development of twenty-first century competences, listing collaboration, critical and creative thinking, problem-solving and applying knowledge as valuable to their own learning. Many of them also considered the learning skills that their students would need in the future.

Introduction

The Cross-Nation Capacity Building in Science, Technology, Engineering and Mathematics (STEM) Education Workshop was held in the Regional Institute of Education (RIE), Bhopal, and aimed at engaging female pre-service teachers in three Makerspace-type STEM activities that provided them with opportunities to create and learn through practical experiences. The program was conducted by researchers from Curtin University, Australia with support from the principal of the Institute and his academic team, including teachers from the Demonstration Multipurpose School on the RIE campus. Fifty-two female pre-service teachers from RIE under-

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going a dual Bachelor of Science, Bachelor of Education program and studying in their 3rd and 5th semesters participated in a series of three pre-service teacher (PST) workshops and three classroom-based workshops.

This chapter examines the literature around STEM education and gender, with a focus on STEM programs, and how a Makerspace approach supports the development of female pre-service teachers' skills, both personally and professionally, through a series of workshops and classroom experiences. Specifically, the research questions underpinning the project were:

(1) How was the Makerspace Project enacted in the Indian context?
(2) How effective was the Makerspace approach in supporting PSTs' engagement and self-confidence in STEM education?
(3) What 21st century competencies did the PSTs identify and demonstrate as a consequence of their participation in the project?

Background

Education in India

India is immensely diverse in terms of geography and it has a rich cultural heritage and ethnic background, a vast and diverse population, cuisine, language, religion, weather, economic status and above all education. India has the second largest population in the world, 1.3 billion people, and has about 2.5% of the Earth's total land mass (Mattyasovszky, 2017). It is one of the fastest growing economies in the world and has the highest number of youth, with an average age of 26.6 years and with 65% of the population below 35 years of age. India is fast improving in several human indices such as life expectancy (now ~68 years), literacy rate (now ~72%) and elementary education enrolment level (UNDP, 2015). Whilst historically it has had significant influence on science, technology and literature, it also has one of the largest populations of illiterate and malnourished people. India is still struggling with high maternal and child mortality rates and 21% of the population lives under the poverty line of $1.90 US per day (UNDP, 2015).

Due to its population, India has voluminous provisions for education at all phases of schooling. There are more than 1.5 million schools with over 260 million students enrolled and at a tertiary level, it has about 864 universities, 40,026 colleges and 11,669 institutes that cater for 3.57 million tertiary students. To address these issues *The Right of Children to Free and Compulsory Education Act*, which was sanctioned on 1st April 2010, encourages students to attend school (Government of India, Gazette of India, 2009). The Act requires all private schools (except minority institutions) to reserve 25% of places for poor and disadvantaged children (to be reimbursed by the state as part of the public-private partnership plan). Children are admitted into private schools based on caste-based reservations. It also prohibits all unrecognised schools from practising, and makes provisions for no donations or capitation fees and no interviews of the child or parent for admission (Nanda, 2017).

The Union Budget determined an outlay of Rs 79,685.95 *crore for the education sector for the financial year 2017–18, an increase from Rs 72,394 crore in 2016–17, a 9.9% rise (Nanda, 2017). According to the same report, of the total outlay, Rs 46,356.25 is for the school sector and the rest for higher education. *Sarva Shiksha Abhiyan*, the flagship central scheme for the universalisation of school education, has been given Rs 23,500 crore. The mid-day-meal programme has been allocated Rs 10,000 crore, up by Rs 300 crore from the last budget (Nanda, 2017). *crore is 10 million rupees (Rs).

In India, education is controlled by each state as well as centrally through the government in Delhi. Each state has its own Board of Education and is also controlled by an organisation under the central government, namely the Central Board of Secondary Education (CBSE), that is responsible for conducting the public exams for Classes X and XII. In addition, for curriculum-related matters including the designing and printing of textbooks, each state has a State Council of Educational Research and Training (SCERT) while, for the country, there is the National Council of Educational Research and Training (NCERT) (Sharma & Sharma, 2015). Besides this, the Council of Indian School Certificate Examination (CISCE) offers an Anglo-Indian pattern of school education in India and conducts three examinations at Classes X, XII, and for Vocational Education (CVE, Class/Grade 12). To cater for the needs of students who cannot undertake regular schooling, the National Open School or the National Institute of Open Schooling (established by the Government of India in 1989) provide opportunities to undertake public exams after studying through distance mode (Sujatha, 2002). Other than this, several religious boards also exist in India. Currently-e-learning has developed rapidly in India to enhance possibilities through education and, due to its large population, India has become the second largest market for e-learning after the United States of America.

Science Education

In India, education is divided into six major stages beginning with pre-school (age group 2–5 years), primary school (age group 6–10 years), and secondary school (age group 11–18 years). Science is taught individually at lower secondary level as an integrated whole rather than as a compartmentalised discipline (Ghosh, 2014). Discipline-oriented teaching and learning commences at XIth and XIIth standards, corresponding to the age group of 16–18 years. While curriculum is common to all students, without specialised subjects, until Class X, students select specific streams (science, humanities, commerce or vocational courses like pharmacy) only at the higher secondary levels (Class XI–XII) (Manna, 2017).

In recent years the trend has been to provide increased content to students through the simple reading of textbooks and answering text-based questions. The over-burdening of the science syllabi is regularly legitimised by referring to the overwhelming amount of new content being created and stating that the syllabi need to grow to keep up with the times. The use of laboratories starts in secondary school, only after middle school, and teachers find that they lack the time to conduct demonstrations as more emphasis is on completion of the syllabus (Chunawala & Natarajan, 2012). Students are not encouraged to learn content through participation in hands-on activities and, as a consequence, they need to memorise facts to pass exams (Science Academies to The Honourable Prime Minister of India, 2017). Any change to either the over-burdened science curricula or rote learning is seen as a weakening that will negatively influence India's competitiveness (Manna, 2017). The introduction of science education as an arrangement of facts to be presented goes against the very premise of science as a creative and dynamic approach to explaining the world.

With the introduction of education for all through programs like *Sarva Shiksha Abhiyan* and *Right to Education*, the education of children up to the age of Class VIII has become a reality. However, a review of the curricula and pedagogical practices of science teachers in India suggest that the ultimate aim of science teaching is to produce scientists who have all the facts learnt through memorisation (Science Academies to The Honourable Prime Minister of India, 2017). The syllabus is dominated by compartmentalised sections of different branches of science and the content has been extended to cover more at an early age. No effort is made to make the content more practical by providing opportunities for hands-on learning. Thus, the emphasis remains on the product and not on the process (Science Academies to The Honourable Prime Minister of India, 2017).

STEM

The term STEM (science, technology, engineering, and mathematics) has become a catch cry for many countries of the Western World, in particular the United States, where the acronym was coined, the United Kingdom and Australia, where millions of dollars have been poured into developing STEM. Businesses and governments have argued that STEM will solve a multitude of 'big problems', prevent countries from entering into recession and help in maintaining their global competitiveness (Blackley & Howell, 2015). Whilst these claims seem excessive, there is a STEM skills shortage and the demand of STEM-skilled graduates is predicted to increase over time (Beede et al. 2011). Whilst there is widespread agreement that STEM will solve major problems and millions of dollars continue to be spent on STEM initiatives, there is a little consensus of the types of skills that are valuable and how they can best be developed in classrooms. In this chapter the term STEM skills are recognised as twenty-first century skills. It is noted that various terminologies are currently used to capture, organise and name this cluster of competences including 'twenty-first century skills', 'key competencies' (OECD, 2005), and 'soft skills'. 'twenty-first century skills' is widely used, but many argue that the skills and capabilities referred to were important well before the twenty-first century, while also noting that with rapid change, century-long milestones are inappropriate.

Table 1 Comparison of twenty-first Century Framework (Partnership 21, 2008), the International Society of Technology Education (ISTE) (2016, 2017), and the UNESCO pillars of education (United Nations Educational Scientific and Cultural Organisation, 2017)

21st century competencies	ISTE standards	UNESCO
	Empowered Learner: leverage technology to take an active role in choosing, achieving and demonstrating competency in learning goals, informed by learning sciences	**Learning to know**: to provide the cognitive tools required to better comprehend the world and its complexities, and to provide an appropriate and adequate foundation for future learning **Learning to do**: to provide the skills that would enable individuals to effectively participate in the global economy and society **Learning to be**: to provide self-analytical and social skills to enable individuals to develop to their fullest potential psycho-socially, affectively as well as physically, for an all-round 'complete person **Learning to live together**: to expose individuals to the values implicit within human rights, democratic principles, intercultural understanding and respect and peace at all levels of society and human relationships to enable individuals and societies to live in peace and harmony
	Knowledge Constructor: curate a variety of resources using digital tools to construct knowledge, produce creative artefacts and make meaningful learning	
	Digital Citizen: Students recognise the rights, responsibilities and opportunities of living, learning in an interconnected digital	

(continued)

Table 1 (continued)

21st century competencies	ISTE standards	UNESCO
Creativity and Innovation • Use a wide range of idea creation techniques, create new worthwhile ideas • Elaborate, refine, analyse and evaluate ideas to improve and maximize efforts • Be open and responsive to new and diverse perspectives; incorporate group input and feedback • Demonstrate originality and inventiveness in work and understand the real-world limits • View failure as an opportunity to learn; creativity and innovation is a long-term, cyclical process of small successes and frequent mistakes • Act on creative ideas make a tangible and useful contribution to the field	**Innovative Designer**: Students use a variety of technologies within a design process to identify and solve problems by creating new, useful or imaginative solutions	
Critical Thinking and Problem Solving • Use Systems Thinking analyse how parts produce outcomes in complex systems • Make Judgments and Decisions • Effectively analyse and evaluate evidence, arguments, claims and beliefs • Synthesise and make connections between information and arguments • Interpret information and draw conclusions based on analysis • Reflect critically on learning experiences and processes • Solve different kinds of non-familiar problems in conventional and innovative ways • Identify questions clarify various points of view better solutions	**Computational Thinker:** Students develop and employ strategies for understanding and solving problems in ways that leverage the power of technological methods to develop and test solutions	

(continued)

Table 1 (continued)

21st century competencies	ISTE standards	UNESCO
Communication • Articulate thoughts and ideas effectively using oral, written and nonverbal communication skills in a variety of forms and contexts • Listen effectively to decipher meaning, including knowledge, values, attitudes and intentions • Use communication for a range of purposes (e.g. to inform, instruct, motivate and persuade) • Utilise multiple media and technologies, and know how to judge their effectiveness a priori as well as assess their impact	**Creative Communicator**: Students communicate clearly and express themselves creatively for a variety of purposes using the platforms, tools, styles, formats and digital media appropriate to their goals	
Collaboration • Demonstrate ability to work effectively and respectfully with diverse teams • Exercise flexibility and willingness to be helpful in making necessary compromises to accomplish a common goal • Assume shared responsibility for collaborative work, and value the individual contributions made by each team member	**Global Collaborator**: Students use digital tools to broaden their perspectives and enrich their learning by collaborating with others and working effectively in teams locally and globally	

In Table 1 we considered these competencies by bringing together the 21st century competencies based on the *21st Century Framework* (Partnership 21, 2008), the International Society of Technology Education (ISTE) (2016) standards for students and for pre-service teachers (2017), and the UNESCO pillars of education (United Nations Educational Scientific and Cultural Organisation, 2017).

STEM in India

STEM Education has gained a considerable amount of attention in recent years (Narasimha, 2008). Due to its size and capacity, India creates large numbers of researchers in all areas of the STEM fields and professions (The World Bank, 2018). In the last decade, many STEM training organisations have been created, offering STEM programs to school students, graduates and as in-service courses to teachers.

Through these STEM programs students are engaging in hands-on learning in robotics, where they investigate and apply basic concepts like wheels, rigging, machines and systems; using advanced science labs with 3D printing; tinkering labs; and producer space labs.

Recent examples of initiatives in STEM education include:

1. *Innovation in Science Pursuit for Inspired Research* (INSPIRE) program, sponsored and managed by the Department of Science and Technology, for attracting young talent to the exciting creative pursuit of science as a career option in order to build the required critical human resource pool for strengthening and expanding the Science and Technology system and Research and Development base in the country. The INSPIRE Scheme consists of three components: (a) *Scheme for Early Attraction of Talents for Science* (SEATS), (b) *Scholarship for Higher Education* (SHE) and (c) *Assured Opportunity for Research Careers* (AORC). The target is to enrol 2,000,000 school children in the age group of 10–15 years, offer INR 5000 per child as scholarships and spread the awardees countrywide (Innovation in Science Pursuit for Inspired Research, 2017).
2. *Kishore Vaigyanik Protsahan Yojana* (KVPY) is an on-going national program of fellowships in basic sciences, initiated and funded by the Department of Science and Technology, Government of India, to attract exceptional and highly motivated students to pursue basic science courses and research careers in science (Kishore Vaigyanik Protsahan Yojana, 2017).
3. *Homi Bhabha Centre for Science Education* has been made the country's nodal centre for Olympiad programs in mathematics and science. The program aims at promoting excellence in science and mathematics among pre-university students (Olympiads: Homi Bhabha Centre For Science Education, 2017).
4. *NITI Aayog* (National Institution for Transforming India), Government of India has established the Atal Innovation Mission (AIM) as an initiative to promote innovation and entrepreneurship across India. It has been based on a study of the innovation and entrepreneurial needs of India for the years ahead (Atal Innovation Mission, 2018).

STEM and Gender

Many women and girls around the world are excluded from participation in science and technology activities by poverty and lack of education (at all levels), or by aspects of their legal, institutional, political and cultural environments. In 2007 the UNESCO publication, *Science, Technology and Gender: An International Report*, stated that there was a positivity about the levelling of the science and technology playing field, with both gender equality and education being part of a United Nations General Assembly resolution and the UNESCO Sustainability Goals (SDGs). So, why then in 2017 are young women still so poorly represented in research and in science, and in STEM research especially? (United Nations Educational Scientific and Cultural Organisation, 2007, 2017). This research program, not just in India but also in Indonesia and Australia, focused on developing the confidence and competence of young female pre-service teachers who worked with both male and female primary students. The female researchers and Indian female academics provided valuable role modelling (Chapple & Ziebland, 2018).

A **Makerspace** *Approach*

The turn of the twenty-first century signalled a shift in the types of skillsets that have real, applicable value in a rapidly advancing world. Makerspaces are increasingly being heralded as opportunities for learners to engage in creative, higher-order problem solving through hands-on design, construction, and iteration (European Union, 2015). Employers are reporting that graduates who are able to solve problems and be critical and creative thinkers will be more versatile and more agile in a rapidly changing world (United Nations Educational Scientific and Cultural Organisation, 2017). This has resulted in a number of new standards being produced and disseminated that focus on skills and knowledge application rather than knowledge acquirement (Partnership 21, 2008; The International Society of Technology Education (ISTE), 2016).

'Makerspace' has been developed organically from online *Hackspace* (Copyright © 2016 London Hackspace Ltd.) or *FabLabs* (Copyright © 2015 Fab Foundation) to an actual physical place termed a 'Place for Making' or Makerspace (Smith, Hielscher, Dickel, Söderberg, & van Oost, 2013). Originally the Makerspace consisted of workshops of artists creating individual artefacts which extended into knitting or crocheting circles and subsequently into schools.

Table 2 Points of difference between traditional Makerspaces and the Makerspace approach (Blackley et al., 2018)

Traditional Makerspace—recreational activity	Makerspace approach—targeted learning activity
Makers create their own communities	Makers are organised into pre-determined communities
Makers choose materials at their own discretion	Makers are provided with a base-level kit of materials
Makers envisage and produce individual, often unique, artefacts	Makers are shown a completed base-level and operational (as appropriate) artefact and are challenged to construct a similar artefact
Makers are not mentored	Makers are mentored (not instructed)
Makers might evaluate their artefact	Makers are scaffolded to evaluate their artefact
Makers might be cognisant of underlying science, technology, engineering, mathematics or other concepts	Makers are made aware of related underlying science, technology, engineering, mathematics or other concepts in line with curriculum documents

The project reported in this book chapter employs a 'Makerspace approach' (Blackley, Rahmawati, Fitriani, Sheffield, & Koul, 2018) that is distinct from Makerspace in its original intent.

> A Makerspace approach sees makers situated in groups of peers mentored through a scaffolded approach to produce a designated artefact. Whilst there is the opportunity for modifications and the demonstration of individuality the goal is for each maker to end up with a complete and workable artefact that they can take home. This approach also has a definite and explicit focus upon the science, engineering and technology concepts involved, and the mentors are encouraged to use correct terminology as they question and support the school students. (Blackley et al., 2018, p. 231)

Table 2 highlights some of the key differences identified in a targeted Makerspace learning activity.

Research Design

The methodology for this project was interpretivist qualitative research, based on an exploratory case study to examine pre-service teachers' engagement with and reflections on a Makerspace approach to creating STEM artefacts—in this case *Wiggle bot, Catapult and Pipeline activities.* The research employed a paper-based survey (see Appendix A) of PSTs' engagement, followed by open-ended questions and observations to verify PSTs' engagement and reflections during the project. The survey items and open-ended questions were developed and validated during the previous research conducted in Indonesia and in Western Australia by the research team (Sheffield & Blackley, 2016).

Context

The participant pre-service teachers (PSTs) were studying and living on campus at the Regional Institute of Education (RIE), Bhopal. The RIE is a constituent unit of the National Council of Educational Research and Training (NCERT), New Delhi, and focuses on teacher education and other educational requirements of the States of Chhattisgarh, Goa, Gujarat, Madhya Pradesh, Maharashtra and UTs of Dadra and Nagar Haveli, Daman and Diu. All students and some faculty live on the extensive campus in Bhopal. The Demonstration Multipurpose School on the campus is a laboratory school for Grades I to XII where students are taught by experienced primary and secondary teachers, thus providing an environment for PSTs to hone their teaching skills. The students in Grades V and VI included both boys and girls and worked in groups with a PST supporting them to complete the activities.

Pre-service Teachers

Fifty-two female pre-service teachers undergoing the dual B.Sc., B.Ed. program and studying in their 3rd and 5th semesters volunteered to participate in the workshops. Each PST was given a STEMinist t-shirt so that they would feel that they were part of this global project and called themselves STEMINISTS. All PST participants were living on the campus at RIE, Bhopal and the classes for that week had been cancelled to enable them to participate in the program.

Method

The Indian STEMinist program was implemented as shown in Table 3, with the phases following the Reflective STEMinist Identity Formation Model (Fig. 1) that was developed from the *Reflective Identity Formation Model* (Sheffield & Blackley, 2016). The phases for each activity were split, with phases one and two completed at RIE on the first two days in Bhopal, and then phases three and four completed at the Demonstration Multipurpose School.

Reflective STEMinist Identity Formation Model

Whilst it is acknowledged that in this instance the model only supported the 'development' of STEMinist identity during this short programme, the more substantial long-term STEMinist project in Australia did contribute to the ongoing development of pre-service teachers' identity as STEMinists. This model includes two iterations

Table 3 Description of dates of the activities in the Indian STEMinist Program

Day	Activities	Where	With whom
14/11/17 9–11.30 am	Wiggle bot 1. Makerspace 2. Personal Reflection	RIE, Bhopal	Pre-service teachers (PSTs) University teacher educators (TEs)
14/11/17 2–4 pm	Catapult 1. Makerspace 2. Personal Reflection	RIE, Bhopal	Pre-service teachers (PSTs) University teacher educators (TEs)
15/11/17 9–12 am	Pipeline 1. Makerspace 2. Personal Reflection	RIE, Bhopal	Pre-service teachers (PSTs) University teacher educators (TEs)
PST Survey			
16/11/17	Wiggle bot 3. Makerspace	Demonstration Multipurpose School	Pre-service teachers (PSTs) students of classes V and VI
14/11/17	Catapult 3. Makerspace	Demonstration Multipurpose School	Pre-service teachers (PSTs) students of classes V and VI
17/11/17	Pipeline 3. Makerspace 4. Professional Reflection	Demonstration Multipurpose School	Pre-service teachers (PSTs) students of classes V and VI
PST Focus Group Interview			

of *the Makerspace Approach* phases. First, a technical, hands-on workshop was presented where pre-service teachers came together to engage in making a series of STEM-related artefacts using a Makerspace approach. They were scaffolded by the Australian research team and the Indian classroom teachers and academics who showed them models as examples and asked questions about their designs rather than provide them with a recipe style step-by-step approach. In this way the pre-service educators were required to make an artefact, similar to the one shown, using trial and error, seeking advice from their peers and using their science knowledge. The first *Makerspace approach phase* was followed by a *Personal Reflection* where pre-service teachers were encouraged to think about how they were demonstrating their STEM skills by answering questions about the underpinning science, mathematics, technology and engineering concepts and to consider how they learnt during the process.

The PSTs were exposed to a pedagogical approach to integrate science, mathematical, technological and design processes that also incorporated probing questions, creativity and innovative thinking, problem-solving, communication and collabora-

Fig. 1 Reflective STEMinist Identity Formation Model

tion. Through the second *Makerspace Approach* phase, the PSTs created a hands-on technical workshop in a primary classroom, mentoring the school students to successfully create the same product, through a trial and error approach, whilst provided with a model. The second *Makerspace Approach* phase was followed by a *Professional Reflection* during which data were collected on the primary students' engagement and understanding of the STEM concepts as well as on pre-service students' reflections about their enactment of the mentor role and what they had learned about themselves as teachers (Blackley, Sheffield, Maynard, Koul, & Walker, 2017).

Data Collection

Three sets of data were collected:

- Three sets of anonymous surveys with 52 pre-service teachers
- Three sets of anonymous survey data from 160 primary school students
- Focus group interviews from 52 pre-service teachers.

Data were collected from all 52 participating pre-service teachers in the form of an anonymous survey of open-ended questions that they completed after they had undergone the first part of the activities, and before they were in the classroom working with the students. This survey asked the PSTs to comment on their engagement in the Makerspace Project, aspects that they felt were most valuable and the issues that challenged them (Appendix 1). The pre-service teachers also completed a group focus interview as the reflection part of phase four. The items included the following:

(a) How do you feel about experiences as a student? (b) How do you feel about your experiences as a teacher? (c) List an interesting 'teaching moment', and (d) List three attributes that typify twenty-first century competencies.

Data Analysis

The open-ended responses from the surveys were analysed using an aggregation of responses into themes; including problem solving, creative and critical thinking, applied knowledge and collaboration. This was undertaken by an Australian researcher and an Indian researcher independently and the results compared and moderated to ensure consistently. The group responses were analysed in the same way using the aggregation of responses into categories (Elliott & Timulak, 2005).

Findings

The STEM activities were enacted around the *Reflective STEMinist Identity Formation Model* with phases one and two of all three activities in the first two days of the program and phases three and four in the schools of the third and fourth days of the four-day program. The phases are described in more detail in Table 4.

Wiggle Bots

1. *Makerspace Workshop*—The provided material included a paper cup approximately 9 inches deep, a DC motor, batteries, battery holder, felt tip pens, an ice-cream stick and a wooden clothes peg. The pre-service teachers were given

Table 4 Outline of activities and phases

Activity	Phases
Wiggle bot	1. *Makerspace Workshop* 2. *Personal Reflection* 3. *Makerspace Workshop in the classroom*
Catapult	1. *Makerspace Workshop* 2. *Personal Reflection* 3. *Makerspace Workshop in the classroom*
Pipeline	1. *Makerspace Workshop* 2. *Personal Reflection* 3. *Makerspace Workshop in the classroom* 4. *Professional Reflection on all three activities*

one hour to prepare the Wiggle bot and were shown a video to assist them. The PSTs made the initial Wiggle bot, however, most of them were not stable when the power was connected. The PSTs were asked questions about stability, design refinement, and the angle of the legs and how they were positioned.

2. *Personal Reflection*—After the activity, the PSTs were asked questions about the science, mathematics, and engineering involved. The science was focused on the centre of gravity, circuits, chemical energy (battery), electrical energy, kinetic energy, height and mass, and the length of the wire from the battery holder to the motor. The mathematics included angles, length, and geometry (equilateral triangles). The engineering dimensions considered design evaluation and refinement to improve the pattern of movement, and positioning of the battery holder and the legs.
3. *Makerspace Workshop in the Classroom*—The PSTs were sent to designated classrooms where they demonstrated their Wiggle bots to small groups of primary students and encouraged and supported them to make their own versions. Each student was provided with the necessary materials that the PSTs had prepared the day before. The students were very excited to see the working Wiggle bots and enthusiastically engaged in the process of making one for themselves. Initially, the students were somewhat confused as to how to proceed, however, with regular intervention from the PSTs in the form of probing and prompting questions that made them think about the next steps, the students could work out how to progress with their projects. It was an enjoyable and engaging activity for all the students. Some of the students found that the Wiggle bots were not stable and kept falling; they were asked to find the reasons for this and to make necessary adjustments so that their Wiggle bot was stable when connected to the power supply.

Catapults

1. *Makerspace Workshop*—The PSTs were shown a photo of the completed catapult and provided with the necessary materials to construct their own using twelve ice-cream sticks, a plastic spoon and several rubber bands. The PSTs initially worked alone on making their catapults however they later realised that they needed support from their colleagues when trying to attach the rubber bands. Once the PSTs had made their catapults, they selected one person to represent them in a competition to see how far they could project an object. The winner was the PST whose catapult threw a tiny rolled paper ball the greatest distance. The PSTs suggested improvements to their catapults to make the projectiles go further; some of these were related to the construction of the catapult whilst others were related to the operation of the catapult.
2. *Personal Reflection*—When asked about the science concepts, the PSTs discussed potential energy, elasticity, projectile motion, elastic potential energy, kinetic energy, mass, and distance. The mathematics that they suggested was

about angles, units of measurement, distance, control of variables, number of trials, and recording data. For engineering aspects, they concentrated on evaluating and refining the design of the catapult to maximise the distance the projectile travelled.

3. *Makerspace Workshop in the Classroom*—The PSTs demonstrated their catapults to the students and asked them to make their own using twelve ice cream sticks, one plastic spoon and rubber bands. Initially, it was difficult for the students to understand the design of the prepared catapult, however later, when PSTs instructed them to observe the catapult carefully and asked them questions, for example (a) Why do you think there is a base? (b) Why do we need a structure like the two triangles? (c) What is the purpose of the two parallel sticks; the students began making the catapults and experienced success. The students found that it was difficult to tie the rubber bands on their own and asked the PSTs to help them, but the PSTs encouraged them to collaborate with each other. Some of the students who were not able to understand the design were asked more questions for example (a) What should be the position of the sticks? (b) Why is it necessary to tie the rubber bands? (c) What happens if the rubber bands are loose? In a relatively short period of time most of the students had completed their catapult. Students were encouraged to have a competition where the winner would be the students whose catapult projected small rolled up piece of paper the greatest distance. After the competition, those whose catapults projected a lesser distance were asked to hypothesise reasons for this and if possible to improve on the design so that their catapult would throw the load a greater distance. It was noticed that the time taken by the students to complete both projects was less than the time taken by PST's when they were given the tasks. All the students enjoyed the activity and wanted these types of activities to be held frequently in the school.

Pipeline

1. *Makerspace Workshop*—The construction of the pipeline was stipulated by a design brief, and specifications were set for both the PSTs and the primary school students. The pipeline had to be 2 m long, with a right angle, three bends with angles of more than 30° through which a golf ball and ping pong ball could pass without obstruction. The PSTs were provided with six A3 sized sheets of paper and the whole pipeline was to be able to stand alone without any support at the height of a chair, i.e. 50 cm.

The PSTs, in groups of five, were required to plan their design, according to the guidelines, in one hour. They were told that a competition would be held at the end. All of the groups made unique designs, and for most of the groups both the balls travelled through the pipeline without incident, with only two groups out of the twelve groups being unable to make the balls travel through the pipeline successfully.

2. *Personal Reflection*—The science in this activity included the friction of the balls in the paper tubes, the importance of gravity as the balls must travel unaided and the issues around mass and the kinetic energy of the light ping pong ball and the golf ball. The mathematics concepts included measurement, angles, diameter, time, the use of a protractor, and time scheduling. The engineering aspect was the design brief and project plan, as well as evaluation and modifications.

When asked what type of questions they could pose to encourage the students in the classroom, the PSTs suggested that they could ask the students to indicate (a) the 90° angle; (b) How do you use a protractor? (c) At what height should the first pipe be positioned so that the ball has maximum impact of gravity and where should the other angles be made? (d) How will the pipeline stand up? (e) What could be done to keep the model stable? And (f) Why can't we have a system of open pipelines?

3. *Makerspace Approach in the Classroom*—On the fourth day, the PSTs were to instruct the students in making the pipeline. This time there were six students and two PSTs in each group. Each class had five to six groups and they had to make a pipeline which was at least 2 m long, had one 90° angle and at least 3 angles more than 30°. The pipeline should be designed so that a ping pong ball and a golf ball can pass-through it one after the other. Each group was provided with one full-size sheet of art paper and three A3 sized sheets of paper to construct their pipeline. They were also provided with cello-tape, a ruler (1-m-long), a protractor, a ping pong ball and a golf ball.

All the PSTs and students were engaged in the project. This was a more difficult project for the students as there was no model in front of them to view. Initially, the PSTs also found it difficult to explain to the students what was expected of them as the students were not aware of measurement and angle in a practical, hands-on sense, although they had studied it in their textbooks. Gradually, as the project proceeded, the students started thinking and reasoning, with the help of the questions from the PSTs, and prepared individual components of the pipeline and checked whether the balls passed through them. Some found that the balls were not moving and rectified the mistakes in the design. Later they tried to join the sections with cello-tape and measured the angles with the protractor. Then they tried to make the balls pass through the pipelines, although many were unsuccessful. However, when the students became frustrated the PSTs motivated them, urging them to find reasons why the balls became stuck and then use these to refine their designs.

The pipeline activity needed a lot of patience on the part of the PSTs, and resilience and perseverance on the part of the students. After about two hours, most of the groups were ready for the competition in which a moderator launched the balls through the opening in the pipelines. The groups were graded on the length of the pipeline, the 90° angle, three angles of more than 30°, and the instances when the ping pong and the golf ball passed through the pipeline. In each class there was at least one group whose balls did not pass all the way through the pipeline. They were asked to rework the design.

4. *Professional Reflection*—The PSTs did not reflect at the end of this activity due to time constraints, however, they reflected with their student groups about all the activities: Wiggle bot, Catapult and Pipeline. The PSTs then reflected together on their pedagogical approaches and what they had learned.

The primary school students commented to the PSTs that they had learnt how to concentrate and demonstrate teamwork, sharing and cooperation. They had learnt to respect other's view points and that there could be more than one way of completing a task. When asked what was the science involved in the activities, the students were able to identify force, friction and gravity, and they learnt how to make a connection between the source of power in the Wiggle bots and its motion patterns. They also identified that if they put the pens inside the paper cup, the pattern created on the paper was different than when they were attached outside the cup, understanding that this design variance impacted on the outcome. The position of the motor and the battery holder also affected the movement and students sought to apply this knowledge (Harlen & Qualter, 2009). In all of the activities, the students correctly identified the mathematics that they had used, including measurement of length, angles, and diameter, and they used a protractor to determine the correct angle.

For the pipeline specifically, when asked about the engineering involved, the students discussed the key aspects of design, they considered why the pipes were enclosed and not left open and recognised that these conversations could have real-life applications. They could see that if the pipes are left open the water supply could be contaminated, mosquitoes would have ready access to breed and vast quantities would be lost due to evaporation. The students also volunteered that, during the course of the preparation of the pipeline, they found that the greater the slope of the pipe the more easily the balls moved. The students said that, when joining the pipes together, they needed each other's help which taught them that, when working together, tasks become easier and stated that 'friendships become stronger'. They also stated that they had learnt that each person had strengths and weaknesses, so they needed to accept friends as they are as no one is perfect. They also expressed that they understood that every activity was an opportunity to learn and they should try to make the most of it.

Survey Data

After the PSTs had experienced all of the activities, and prior to them going to the schools, they participated in a survey (see Appendix 1). The first question asked the PSTs to indicate what aspect of the project they had enjoyed. All the PSTs responded positively that they had enjoyed the project and some offered multiple perspectives (as a consequence $N = 79$ from a participant group of 52) (Table 5). Twenty-six percent of PSTs reported that they enjoyed working with their peers, with one PST commenting, 'I enjoyed, because it was teamwork, and also it was interesting, something which I haven't done before'. Twenty percent of PSTs enjoyed the hands-on aspect of the

Table 5 Response to question 'What was the aspect that you most enjoyed?'

Category	*N*	%
Collaborating	20	26
Applying science and maths	9	11
Problem solving	11	14
Hands on activities	16	20
Pedagogical skills	4	5
Engagement	10	13
Creativity	9	11
Total	79	100

learning, with one PST stating that, 'It is the most creative learning project. It really teaches us to use the science, technology, engineering and mathematics in our daily life', adding that the hands-on approach was unique and that she could see all the STEM aspects and how they work together.

When the PSTs were asked about the aspects they felt were most valuable, they reported that working in their groups and solving problems together had been the most valuable experiences (Table 6). Twenty-nine percent of comments in this category related to collaboration and a further 23% to problem-solving, with one PST summing up, 'Problem-solving and collaboration to solve a problem with cooperation and team is most valuable'. Another student acknowledged, 'Forcing us to think on our own. Motivating constructivism helps us to apply our knowledge and learn from ourselves'. So the PSTs were able to see the value of the activities in supporting their learning. It was interesting to note that one PST looked at the bigger picture and commented, 'The concept of STEMinist was the most valuable because it supported the women to come forward and show their skills', which articulated the ultimate goals of the Australian researchers.

Finally, PSTs were asked to document the major challenges they experienced and 30% spoke specifically about issues with the Pipeline activity in including the number and size of the angles that were in the specifications and the use of the

Table 6 PST responses to the question 'What aspects did you find the most valuable?'

Category	*N*	%
Collaborating	22	29
Applying science and maths	13	16
Problem solving/critical thinking	18	23
Hands on activities	6	7
Pedagogical skills	7	8
Time management	2	2
Creativity	10	13
Other	2	2
Total	80	100

Table 7 PST response to the question 'What aspects did you find the most challenging?'

Category	*N*	%
STEM activity specific issues	20	30
Applying science and maths	8	12
Problem solving/critical thinking	13	19
Collaboration	8	12
Resource scarcity	6	9
Time management	6	9
Creativity	3	4
Other	3	4
Total	67	100

materials (Table 7). They commented on the time constraints for all the activities and how having limited resources was also an issue. A very articulate student summed up the challenges of the activities, 'The project required High Order Thinking Skills. We had to think out of the box and that our teammates had their own opinions'.

Interview Data

The focus group responses were categorised into two sets: (1) the PSTs as learners (Table 8), and (2) the PSTs as educators (Table 9). With regard to the first category, they generally outlined how much they enjoyed doing the simple activities and how much easier they perceived learning was in this context. They reported being interested and motivated, and could see value in using a hands-on approach to apply their STEM knowledge.

With regard to the PSTs as educators, they articulated the challenges they had with trying to facilitate learning through a constructivist approach rather than a didactic, more positivist approach. They could see value in this method of teaching but were challenged by some of the behavioural issues that arose when students were motivated, excited and enjoying their learning. It was interesting to note that, by working with small groups of students, the PSTs were able to see that students had a range of skills and abilities and learning styles that they recognised and needed to consider. One group commented, 'We saw that different students had different ideas and approaches to finish the given tasks and they have their own creativity in it which was very interesting to see as a teacher'.

A focus group discussion was held with the PSTs at the conclusion of the week and they were asked about their experiences. All unanimously reflected that the performance of the students was better than their own, as the students first, took less time in preparing the projects and second, they had better ideas and made projects with unique and creative designs. The PSTs noted that creativity was not dependent on academic achievement. They said that they had asked the students who were

Table 8 The focus group interview questions from the PSTs collated around them as learners

Criteria	Group 1	Group 2	Group 3	Group 4	Group 5
How do you feel about experiences as a student	Applying STEM, integrating, problem-solving, hit and trial (keep trying all possible ways), teamwork, understanding everyone's perspective	Learning anything theoretically is not as effective as learning practically. It really builds up our concepts and helps in gaining effective knowledge about the subject. Learning something practically is easy and fun thing to do then to just mug up (sic)	The activities were quite interesting, and we enjoyed a lot while doing them. We applied STEM at the same time. We performed every activity in different forms the focus was to learn the concept behind every activity with some creative ideas	Interesting, learn management skills, got to know where we lack, twenty-first century skills we learn through them	We were very curious about doing the activities, use of STEM in existing stuff which are even simple was enjoyable, we learned about the importance of teamwork and motivating each other throughout any process/activity as it will increase the progress of the project, time management is ultimately the most important
What was the best thing you discovered as a student	My patience with numerous failures and attempts, keeping cool, being focused on the task	The best thing we discovered was the victory they have earned. They were really motivated with the reward. The feeling of success	In every activity we discovered different concepts involving STEM	It is important to apply the concepts that are presented in the books	Uses the concepts of STEM in basic things which are fun and used in daily activities. Experiential learning gives best results

Table 9 The focus group interview questions from the PSTs collated around them as educators

Criteria	Group 1	Group 2	Group 3	Group 4	Group 5
How do you feel about experiences as a teacher	Directing students towards goal not telling directly, motivating students, understand their point of view, handling them delicately	To handle the students is the most difficult part of being a teacher. Not to help them and to let them do things on their own as a teacher to keep them motivated is a big deal	Doing these activities with students was a major task. Understand the concept behind the activities and motivate them to do the activities by themselves. As a teacher we enjoyed a lot and also learned new ideas from students	Frustrated at times, felt responsible, it is important to let the student discover the science on their own. It is important to teach 21st century skills through activities	Taking the knowledge to the level of the student is the most important part of the activity
List an interesting 'teaching moment'	Learning with them or from them, innocent fun	To make them distribute the work amongst them for better performance, to make them work in teams, to not to help them	Completion of tasks successfully students cheer up	When a student has already reached to the conclusion and has understood everything while few still struggling with what things were about we have to take a different path to make them learn	We saw that different students had different ideas and approaches to finish the given tasks and they have their own creativity in it which was very interesting to see as a teacher

(continued)

Table 9 (continued)

Criteria	Group 1	Group 2	Group 3	Group 4	Group 5
What was the best thing you discovered as a teacher	Students can be creative and innovative without telling instructions, when my students finally succeeded in the task	Girls said if we do something with determination and concentration we can do anything. It really touched our hearts	Practical use of every theory students learn the concept clearly	Students observe teachers very carefully in class and teachers should be aware of the behaviour with students as it affect them a lot	Every child has different learning styles and different creativity level which is best in their own way
3 attributes in terms of 21st century competences	Patience, understanding students Listening to students	Practical knowledge, discipline, endurance and patience	Constructivist approach, motivation positive re-enforcement	Motivates, gender equity social equity	Motivation Management Team work

considered the ‘best’ in the class but found that these students were not always very creative. Some students who were not talented academically surprised them, both with the speed of completion and the way in which they developing strategies from situations in which they were initially challenged. Many also worked towards making designs that were different from the ones that were shown to them. The PSTs queried them about whether the alternate design would work but the students were keen to try them and further refine their ideas. Many were sure that the alternate design would be better and would fulfil the specifications.

They also learnt that the students were more eager than the PSTs to try something different when they were stuck, and they recognised that there can be other approaches. The PSTs were continually reflecting on how to support the students to apply their understanding of concepts in the particular situation and how to make the activity more meaningful. The PSTs learnt that, through engaging activities, learning can take place and creativity can be developed. They also learnt that patience, guidance, perseverance and a desire to genuinely help the students learn are key aspects that need to be developed as an effective teacher. They also determined that students need to be regularly motivated and that constructive criticism helps in the positive growth of the students. Finally they expressed the opinion that the activities were a wonderful method for developing 21st century competencies such as cooperation, reasoning, time management, problem solving, team work, precision, accepting defeat and rejection, thankfulness, collaboration, respect for others, listening and accepting others viewpoints, accepting what is useful and neglecting what is unwanted, concentrating even when facing failures and learning from mistakes and rectification.

Conclusions

In this chapter, we posit that the STEM components of these projects, whilst significant, are less significant than the development and demonstration of twenty-first century skills or competencies. In Table 9 we considered these competencies by aligning them with the twenty-first century competencies, based on the *21st Century Framework*, and we noted that there are overlaps in these competences, positing that teaching these key skills or competencies can only be completed efficiently by engaging teachers and pre-service teachers in transformative professional learning. The importance of implementing a different approach which allows pre-service teachers more time and opportunities for reflection, as they demonstrate and develop their own skill sets which they can then help develop in their primary students, is stressed.

As stated in the background, Indian classrooms have a very positivist pedagogical approach to teaching and learning, and this STEM program, with a hands-on integrated approach which strongly focused on twenty-first century competencies, really challenged the PSTs’ teaching identity. The program has helped develop a deeper understanding of authentic learning, collaboration and problem-solving skills that can be developed through the Makerspace approach. With regard to the content aspects of science, technology, engineering in the form of design, and mathematics, the PSTs considered these aspects as they participated in the projects themselves in Phase 1 and 2; and in their pedagogy in Phases 3 and 4. The PSTs understood that, although they may have an understanding of the content and concepts, passing it on to the students through activities cannot be done until certain teaching and behaviour management skills are acquired. Lastly, they themselves experienced that, through conducting an activity, various values and skills can be developed among the students.

The fact that they initially struggled with the tasks themselves, gave the PSTs greater awareness of the challenges that the primary students may experience and, therefore, they were able to develop strategies to support them. Moreover, at its inception, the STEMinist program was designed to empower young female primary pre-service teachers, by building their confidence and competence in STEM education, and also to inculcate them into a wider, global community of supportive women. Throughout the developing and developed world women continue to be underrepresented in STEM professions. By engaging and empowering primary PSTs, however, this program may encourage and excite young female students to embrace STEM at school and continue through the pipeline into the STEM professions (Chapple & Ziebland, 2018).

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References

Atal Innovation Mission (AIM). (2018). NITI Aayog (National Institution for Transforming India), Government of India. http://aim.gov.in/index.php.

Beede, D., Julian, T., Langdon, D., McKittrick, G., Khan, B., & Doms, M. (2011). Women in STEM: A gender gap to innovation. States News Service. Retrieved from http://www.esa.doc.gov/sites/default/files/reports/documents/womeninstemagaptoinnovation8311.pdf.

Blackley, S., & Howell, J. (2015). A STEM Narrative: 15 Years in the Making. *Australian Journal of Teacher Education, 40*(7), 102–134. Retrieved from http://dx.doi.org/10.14221/ajte.2015v40n7.8.

Blackley, S., Rahmawati, Y., Fitriani, E., Sheffield, R., & Koul, R. (2018). Using a *Makerspace* approach to engage Indonesian primary students with STEM. *Issues in Educational Research, 28*(1), 18–42. http://www.iier.org.au/iier28/blackley.pdf.

Blackley, S., Sheffield, R., Maynard, N., Koul, R., & Walker, R. (2017). Makerspace and reflective practice: Advancing pre-service teachers in STEM education. *Australian Journal of Teacher Education, 42*(3), 22–35. Retrieved from http://ro.ecu.edu.au/ajte/vol42/iss3/2/.

Chapple, A., & Ziebland, S. (2018). Challenging explanations for the lack of Senior Women in Science? Reflections from Successful Women Scientists at an Elite British University. *International Journal of Gender, Science and Technology, 9*(3), 44–77. Retrieved from http://genderandset.open.ac.uk/index.php/genderandset.

Chunawala, S., & Natarajan, C. (2012). A study of policies related to science education for diversity in India. In *"Towards Effective Teaching and Meaningful Learning in Mathematics, Science and Technology", Proceedings of ISTE International Conference on Mathematics, Science and Technology Education*, South Africa. Retrieved October 2011, from https://www.researchgate.net/publication/256388028_A_Study_of_Policies_Related_to_Science_Education_for_Diversity_in_India.

Elliott, R., & Timulak, L. (2005). Descriptive and interpretive approaches to qualitative research. In *A handbook of research methods for clinical and health psychology*. New York, NY: Oxford University Press. Retrieved from http://www.oxfordclinicalpsych.com/view/10.1093/med:psych/9780198527565.001.0001/med-9780198527565-chapter-11.

European Union. (2015). *Horizon 2020 work programme 2014–2015*. Retrieved from http://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/main/h2020-wp1415-leit-ict_v1.0_en.pdf.

Ghosh, A. (2014). *Indian school education system: An overview*. New Delhi, India: The British Council. Retrieved from https://www.britishcouncil.in/sites/default/files/indian_school_education_system_-_an_overview_1.pdf.

Government of India, Gazette of India. (2009). The Right of Children to Free and Compulsory Education Act, 2009. Part II Section 9. No. 35 of 2009. Government of India, New Delhi.

Harlen, W., & Qualter, A. (2009). *The teaching of science in primary schools*. New York: Routlegde.

Innovation in Science Pursuit for Inspired Research. (2017, December 26). Retrieved from http://www.apastyle.org/learn/faqs/web-page-no-author.aspx.

International Society for Technology in Education. (2016). *The 2016 ISTE standards for students*. Retrieved from http://www.iste.org/standards/standards/for-students-2016.

International Society for Technology in Education. (2017). *The 2017 ISTE standards for pre-service teachers*. Retrieved from http://www.iste.org/standards/standards/for-pre-serviceteachers-2017.

Kishore Vaigyanik Protsahan Yojana. (2017, December 26). Kishore Vaigyanik Protsahan Yojana. Retrieved from http://www.kvpy.iisc.ernet.in/main/index.htm.

Manna, I. (2017). *School level science education system and status in India*.

Mattyasovszky, M. (2017). *The largest countries in the world*. Retrieved from https://www.worldatlas.com/articles/the-largest-countries-in-the-world-the-biggest-nations-as-determined-by-total-land-area.html\.

Nanda, P. K. (2017, February). Union budget 2017: Education outlay increases 9.9% to Rs 79,685.95 crore. Livemint. Retrieved from http://www.livemint.com/Politics/hkjZw2CFY9u4xGHDk6QftN/Union-budget-2017-Education-outlay-increases-99-to-Rs796.html.

Narasimha, R. (2008). Science, technology and the economy: An Indian perspective. *Technology in Society, 30*(2008), 330–338.

OECD. (2005). *OECD economic globalisation indicators*. Paris: OECD.

Olympiads: Homi Bhabha Centre For Science Education. (2017, December 26). Olympiads: Homi Bhabha Centre For Science Education. Retrieved from http://olympiads.hbcse.tifr.res.in/.

Partnership 21. (2008). *Learning for the 21st century*. Retrieved from http://www.p21.org/storage/documents/P21_Report.pdf.

Science Academies to the Honourable Prime Minister of India. (2017). *Action Plan for Harnessing Science and Technology towards Indigenous Self-Reliance*. S. Academies. Retrieved from http://www.ias.ac.in/.

Sharma, S., & Sharma, P. (2015). Indian higher education system: Challenges and suggestions. *Electronic Journal for Inclusive Education, 3*(4), 3–4. Retrieved from https://files.eric.ed.gov/fulltext/EJ1131773.pdf.

Sheffield, R., & Blackley, S. (2016). Makerspace in STEM (MIS) for girls: An Exploratory Study. In *Proceedings of the International Society for Technology in Education (ISTE) 2016 Conference and Expo*. Denver, Colorado, USA.

Smith, A., Hielscher, S., Dickel, S., Söderberg, J., & van Oost, E. (2013). Grassroots digital fabrication and makerspaces: Reconfiguring, relocating and recalibrating innovation? *Science and*

Technology Policy Research SWPS 2013-02. Retrieved from https://www.ioew.de/uploads/tx_ukioewdb/Smith_Hielscher_Dickel_S%C3%B6derberg_Oost_-Grassroots.pdf.

Sujatha, K. (2002). *Distance Education at Secondary Level in India: The National Open School*. UNESCO, International Institute of Educational Planning. 7–9 rue Eugene-Delacroix, Paris.

The World Bank. (2018). *World development report 2018*. Washington, DC: Retrieved from http://www.worldbank.org/en/publication/wdr2018.

UNDP. (2015). *Human development report 2015: Work for human development*. UN Plaza, New York. United Nations Development Programme. Retrieved from http://hdr.undp.org/sites/default/files/2015_human_development_report.pdf.

United Nations Educational Scientific and Cultural Organisation. (2007). *Science, technology and gender: An international report*. France: United Nations Educational Scientific and Cultural Organisation. Retrieved from http://www.unesco.org/new/en/education/networks/global-networks/aspnet/about-us/science,technologyandgender:aninternationalreport/.

United Nations Educational Scientific and Cultural Organisation. (2017). *Cracking the code: Girls' and women's education in science, technology, engineering and mathematics (STEM)*. France: United Nations Educational Scientific and Cultural Organisation. Retrieved from http://www.unesco.org/new/en/education/networks/global-networks/aspnet/about-us/strategy/crakingthecode/.

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

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'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 grassroots 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.

The Changing Nature of Science Classrooms in Indian Schools: A Technology Perspective

Adit Gupta

Abstract Good science teaching is one of the most valuable ways to meet the urgent need for science-educated citizens and workers. Enthusiastic, intelligent, and well-educated science teachers inspire and prepare students to investigate the great questions of science and the questions raised by the scientific discoveries which affect us and our society. Teaching science in schools is undergoing a major transformation today with the advent of technology and ever-increasing focus on providing sufficient time and opportunity for students to perform experiments and conduct activities in the classrooms in order to promote a culture of innovation and entrepreneurship. This paper focusses on three important aspects that are changing the nature of Indian Science classrooms, these are (a) Technology-Supported Classrooms (b) Mobile Learning and (c) Setting up of Tinkering Labs in schools. The effective and appropriate integration of technology in the science classroom creates a dynamic learning environment where students are active participants in the learning process and therefore, science teachers are now matching the appropriate use of technology with content to maximize the student's potential in learning. Students in schools are also being allowed to take the digital interactive science content home and are increasingly using mobile learning devices such as tablets and smartphones to learn at their own pace and time. Apart from focussing on digital-learning, schools are also setting up Tinkering Labs to foster curiosity, creativity and imagination in students; and inculcate skills such as design mindset, computational thinking, adaptive learning and physical computing, etc. These Labs provide a workspace where young students can give shape to their ideas through hands-on do-it-yourself mode; and will get a chance to work with tools and equipment to understand the concepts of STEM (Science, Technology, Engineering and Math). Tinkering Labs contain educational and learning 'do it yourself' kits and equipment on—science, electronics, robotics, open source microcontroller boards, sensors and 3D printers and computers.

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Introduction

Science Education is imperative for making sense of the world, participating in democratic societies, and being a productive citizen. Scientists, leaders in government, industrialists, and the public, in general, need to be able to understand scientific issues and to make effective judgements about them. We need scientifically literate and informed people to make decisions about numerous things such as major government projects in space exploration and medical science; health problems, environmental and pollution problems, such as air and water pollution; diseases such as cancer or tuberculosis and epidemics; or the possible effects of chemical pesticides upon us and our environment. In fact, people with scientific backgrounds are also required to address issues facing society in general and work towards specifically improving the everyday life of the common man, thereby impacting the overall quality of life.

More and more people will need a certain level of scientific knowledge to accomplish various tasks, both at the personal as well as the professional level, and they must depend on teachers to help them get the knowledge they will need. The next generation of youngsters, as it passes through school, must be well educated in and about science to enable them to prosper in our democratic society. Moreover, ever-increasing scientific and technological progress challenges man's ingenuity to improve methods of processing, retrieving and reporting all sorts of scientific information. In a sense, we need a new generation of people who can combine science with other talents and can function in an interdisciplinary environment as, for example, the scientist, librarian and the science reporter.

Effective science teaching is one of the most valuable ways to meet this urgent need for science-educated citizens and workers. Enthusiastic and well-educated science teachers inspire and prepare students to investigate the great questions of science and the questions raised by scientific discoveries which affect us and our society. Mainly through the inspiration of devoted science teachers, great numbers of students develop lifelong scientific interests and learn to appreciate and understand the nature of science and its usefulness to mankind (Ediger & Rao, 1996).

I have been associated with the educational process at the school level for the last 25 years in the city of Jammu which is located in the northern part of India. I started out as a science teacher at the secondary level and then went on to become the principal of a higher secondary school having over 1100 students. During my stint as a teacher and as a principal, I have observed the evolution in science teaching that has been happening in our classrooms. From teaching through the chalk and talk method to using non-interactive teaching aids such as models and charts, to the present use of technology in explaining scientific concepts to students, both I and my science teachers have used numerous techniques to capture and maintain learner attention and interest. Unless the students' interest is being maintained, the chances are that learning will not accrue as it should. Hence it is important that science teachers provide initiating experiences which engage the learner actively, as it is important for students to attend to what is being presented for more optimal learning to occur. With the integration of technology in day-to-day teaching and learning in the science classroom, the students have been found to be more curious and interested in learning. Teachers also have found it convenient to prepare and discuss the content using multimedia technology and the classroom environment has become more interactive and lively. One major advantage of using technology in the classroom has been that the teacher plays the role of the facilitator and helps students learn at their own pace and convenience.

Technology takes a special place as a powerful tool in classroom learning. Children's traditional classroom tools—pencils, notebooks, and texts—are still vital, but for children to make sense of and modify their ideas or access and study information, however, they are inadequate by themselves. Computers, tablets, mobiles and other technologies may help children in making sense of new concepts and trying out novel ideas. Thus, it is important to understand that it is not what equipment is used in the classroom, but how that equipment is used that will make the difference. Technology must be thought of as an integral component of the curriculum, a tool that can supplement almost any content. Technology makes possible the instant exchange of information between classrooms as well as individual students; it allows instant access to databases and online information services, and provides multimedia technical resources such as interactive audio and video. Technology also allows for transforming of pre-existing educational materials across media formats: print, static illustrations, still and digital photographs, digital audio, still and motion video, still and motion film, animations, computer graphics, and hypermedia can all be accessed and combined in novel ways (Strommen & Lincoln, 1992).

Educators are of the opinion that new learning and teaching strategies will have to be introduced to prepare students to become independent learners. Technology can provide an opportunity to introduce such strategies. Through the use of technology, teachers can provide opportunities for students to learn, think critically and have discussions with their peers supported by Information and Communication Technologies (ICT). Bitter and Pierson (2002) consider that technology is an agent of change and appropriate use of technologies can make learning for students more interesting and enriching and prepare them for the demands of the workplace. Therefore, it is important that educators seriously consider aligning the appropriate use of technology with content and learning experiences to maximize the student's potential in learning. It is envisaged that teachers will be teaching less and it is up to educators to inspire, motivate, and excite students about the use of technology for learning.

Review of Literature

The review of literature in this section throws light on the contribution of technology in improving the quality of science education in schools. Badia, Meneses, and Sigales (2013) conducted a study to identify the main factors that influence teachers' decision-making regarding the educational use of ICT in technology-rich classrooms. They collected data from 278 teachers in Catalonia (Spain) working in eight primary and secondary schools rich in educational technology. The specific questionnaire used to that end included an extensive range of items to obtain information about the teachers' perceptions' of the factors influencing the use of ICT in the classroom. They identified and characterised five factors that positively influence the educational use of ICT in the classrooms, these were: utility and educational setting, teacher support, availability and access in the classroom, technological expertise and access outside the classroom.

DeCoito and Richardson (2018) explored 74 middle school teachers' beliefs about and use of technology through a technology, pedagogy, and content knowledge (TPACK) lens. They sought to understand how middle school teachers use and perceive technology in practice and the factors influencing their pedagogical decisions to incorporate technology into their practice. Data sources included surveys, administered after a science, technology, engineering, and mathematics (STEM) outreach program and teacher interviews. Findings revealed that both internal and external barriers were present and influenced how teachers situated their pedagogy in terms of technology integration. It was also found that teachers were confident in content, pedagogy, and technology; however, most viewed technology as a tool rather than an embedded part of the learning process. This study contributes knowledge about professional development initiatives and the need to address not so much technology knowledge as the interdependence of technology, pedagogy, and subject content matter.

Minshew and Anderson (2015) in their study observed that many schools are beginning to adopt one-to-one computing with the goal of developing students' twenty-first-century skills, which allow students, not only to learn content, but to acquire critical skills (e.g. creativity, collaboration, and digital literacy) that will lead to future careers. Technology offers teachers the ability to transform the quality of instruction—to achieve a more student-centred learning environment, have more differentiated instruction, develop problem- or project-based learning, and demand higher order thinking skills. A number of barriers and influences have emerged from the findings of this study on teachers' practice and integration of technology into their classrooms. This study examines how these barriers, both internal and external, influence classroom pedagogy. Using a TPACK framework, this study examined the classroom practice of two middle grades mathematics and science teachers integrating a 1:1 iPad initiative and the ways they dealt with the barriers in their classroom practices.

Wilson, Goodman, Bradbury, and Gross (2013) in their study describe a shared common course assignment on forces and motion in an elementary science methods course, in which the iPad was introduced to preservice teachers as a tool for developing understanding of key concepts and processes. The study focused on the aspects of iPad use that 98 elementary preservice teachers perceived as beneficial in the forces and motion unit. Participants discussed the utility of the iPad for recording and replaying test data, its potential for visualising science phenomena, and its value for communicating science understanding. Additionally, participants described how the iPad influenced instructional efficiency, engagement, and social learning.

Montrieux, Vanderlinde, Schellens, and De Marez (2015) investigated teachers' and students' perceptions concerning the impact of using tablet devices for teaching and learning purposes. An explorative focus group study was conducted with teachers ($n = 18$) and students ($n = 39$) in a secondary school that has implemented tablet devices since 2012. The general finding of this study showed that the use of tablet devices in the classroom setting had an impact on both teaching and learning practices. The results suggested that teachers could be divided into two categories: the innovative teachers and the instrumental teachers. Innovative teachers attempted to shift from a teacher-centred to a learning-centred approach. They had changed their teaching style by transforming lessons in accordance with the advantages tablet computers could offer. Instrumental teachers seemed to use the device as a *book behind glass*. The distinction between the two groups had consequences for both the way courses were given and how students experienced them. In general, the introduction of tablet devices entailed a shift in the way students learnt, as the devices provided interactive, media-rich, and exciting new environments. The results of this study indicated that policymakers should consider introducing technical and pedagogical support in order to facilitate both teachers' and students' understanding of the full potential of this kind of technology in education.

Based on the review of literature and my own experiences as a science teacher and a school administrator, I would like to highlight the usage of three technologies that are being used for teaching science in our schools especially those belonging to the Jammu region. These are (a) the technology-supported classrooms also sometimes referred to as Smart-Classes (b) Mobile Learning wherein students use various educational applications (also known as apps) on mobile devices and (c) Tinkering Laboratories where students are taught STEM concepts through a hands-on approach.

Technology-Supported Classrooms

The technology-supported classrooms in our school in Jammu were developed with the purpose of empowering teachers with technology right inside their classrooms. The technology-supported classroom enables teachers in our school to use digital resources such as graphics, animations, 3D Images and Video clips, in addition to the chalk and talk methods of teaching (see Illustration 1). This results in a completely new multi-sensory learning experience for students and helps them to improve their academic performance.

Initially, schools across India set up modern computer laboratories (labs) and audio-visual labs equipped with a video projector and a Personal Computer (PC). The computer labs were used to deliver computer education to students, as per the prescribed curriculum of the school, and educational software was used to help students learn difficult concepts in science and other subjects such as mathematics and geography in the audio-visual labs. Before the introduction of smart classes, the students visited these computer labs or Audio-Video (AV) rooms once or twice a week. This allowed each student to get an exposure of just about 40–50 periods,

Illustration 1 A technology supported classroom setup in our school

with each period being of 40 min duration, during the entire academic session with technology. Students spent nearly half or more of these 40–50 periods in learning IT concepts. Of the over 1200 periods in any given academic year, only 15–20 periods were being used for computer-aided education covering non-Information Technology subjects. In this way, technology did not affect the subject teachers and a student's life in schools. This meant that students were being moderately exposed to technology, only in the computer labs and AV Rooms, and there was no integration of technology in the teaching-learning process in the classroom in any real sense.

The setting up of technology-supported classrooms in our schools helped to integrate technology in the day-to-day lives of teachers and students right inside their classrooms and it affected a significant part of teaching and learning in any given academic session. Figure 1 shows the comparison between the previous use of technology in our schools and the current trend. The graphic on the left shows that teachers were teaching science and other subjects more through the traditional chalk and talk method while the graphic on the right shows the changed scenario after the integration of technology in the classroom where more sessions are being conducted in technology-supported classrooms. The classrooms turn into lively learning platforms for students and the teachers can choose from a mix of teaching tools such as the traditional chalk and blackboard coupled with graphics, sound, animations, and videos.

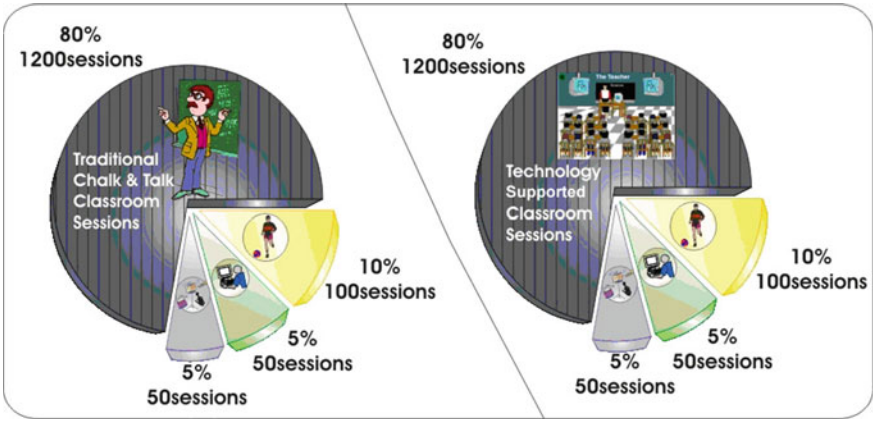

Fig. 1 Comparison of integration of technology in conventional classes versus technology-supported classrooms

The technology-supported classrooms present an array of stimulating interactive 3D modules that bring complex concepts of sciences to life. These modules enhance learning by providing a 360-degree view of concepts in an exciting and engaging manner. The graphically enhanced images together with audio descriptions make the learning experience life-like, allowing students to get involved and enjoy the lessons being taught. In this simulated environment, abstract concepts turn into tangible experiences. All such simulations are designed to match the school curriculum, making lessons relatable and impactful.

For enhancing the learning in science, the technology supported classrooms being implemented in our school usually follow a constructivist approach or the 5E Approach (Bybee et al., 2006) i.e. Engage, Explore, Explain, Elaborate and Evaluate which is described below:

Engage: Learners are engaged in the concept, process, or skill to be learned by making connections between past and present learning experiences.
Explore: Learners actively explore their environment or manipulate materials to identify and develop concepts, processes and skills.
Explain: Learners have opportunities to verbalise their conceptual understanding or to demonstrate new skills or behaviours.
Elaborate: Through new experiences, learners develop deeper and broader understanding of major concepts, obtain more information about areas of interest, and refine their skills.
Evaluate: Learners assess their understanding and abilities; teachers evaluate students' understanding of key concepts and skill development.

The Delivery Model

Technology Supported classrooms have a unique delivery model in our school. A knowledge centre is created inside the school equipped with the entire library and smart class digital content. The knowledge centre is connected to the classrooms through the Internet or the local area network. Teachers get relevant digital resources such as animations and videos, interactive virtual labs tool, etc. and use them as a part of their lesson plans in every classroom period. The classrooms are equipped with custom designed electronic interactive whiteboards, projection systems, PC's. Theses smart classes are implemented in schools by leading educational technology companies completely on a turnkey basis, with schools paying for the hardware and educational content to be used in classes. These classes are powered by a vast repository of digital instruction materials exactly mapped to meet the specific objectives laid out by different state learning standards such as the educational boards of various states or the Central Board of Secondary Education (CBSE). The content repository consists of thousands of highly animated, lesson specific, 3D and 2D multimedia modules. These are built module by module based on the curriculum with a design that allows the teacher to effectively transact the lesson in a classroom at his/her own pace. These modules help the students to understand the concepts easily and interact with other students. The modules are embedded in a template that allows the teacher to teach a chosen lesson in a class, frame by frame, with engaging and instructionally sound animated set of visuals while retaining complete control on the pace of delivery (see Illustration 2). The curriculum reach unfolds from kindergarten to twelfth grade

Illustration 2 A chapter of science being taught through the technology supported classroom

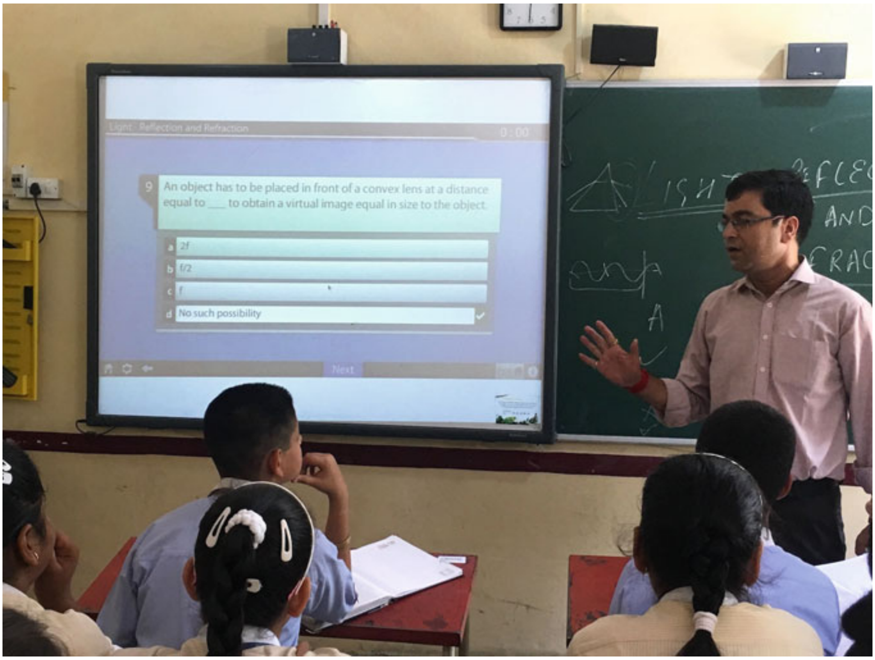

Illustration 3 Assessment of learning using the technology supported classroom setup

covering subjects like mathematics, science, English, EVS, social science, physics, chemistry, biology, history, geography, economics and business studies.

Teachers can also create their own smart tests and use them in the class for assessment. For this purpose, a test authority tool has been added to the smart class assessment application. Students are equipped now with a handheld remote answering device that now forms a part of their pencil box, or they can be assessed using a selection of questions from the vast repository or teacher-developed tests within the technology-supported classrooms. At home, the smart class system works as a virtual school, where parents, teachers and students can communicate with each other. Teachers can upload assignments and make important information available for parents to view (see Illustration 3).

Mobile Learning

The massive amount of information available at one's fingertips has the capacity to allow for in-depth exploration of interests and the use of a variety of textual, visual, and auditory learning experiences. As West (2015) mentions, studies show that students are quite open to using technology for learning and that they are aware of new learning tools such as online courses, virtual reality, and video games for instructional purposes.

Mobile devices provide detailed metrics and data that can lead to instantaneous assessment and feedback on whether or not students are meeting educational goals. The efficiencies of technology can ensure that students who are falling behind get a chance to learn important concepts and students who are ahead do not get bored with material they have already mastered. Using software, teachers can create dashboards to track individual student achievement on his or her learning curve, categorise students and assess what actions should be taken. West (2015) argues that under the status quo in education, neither advanced students nor those requiring extra help are having their needs met in traditional classroom settings.

Traditional lecture-based classroom teaching is now supplemented with technology-enabled learning, and this includes the use of mobile devices. Children as young as primary age interact readily with digital devices such as tablets. Young people conduct their social lives through their phones, and instinctively turn to them first for news, information-sharing and entertainment. By capitalising on familiarity with mobile devices, education can motivate today's children through new and innovative ways of learning. The mobile revolution is here. More and more schools are moving toward mobile learning in the classroom as a way to take advantage of a new wave of electronic devices that offer portability and ease of use on a budget. Netbooks, iPads, cell phones, iPods, e-readers and even Personal Digital Assistants (PDAs) are increasingly becoming the tools of choice for today's educators, and it is easy to see why. Mobile learning has truly revolutionised the way students learn, access and assimilate information. With rapid deployment of mobile devices such as smartphones, Tablets, iPads and touch screen laptops students are able to learn at their own pace and in their own time.

In this section, we will showcase a few mobile learning platforms/applications being promoted in the country both by the government of India and private e-learning companies.

E-Pathshala

E-Pathshala has been developed by National Council for Educational Research and Training (NCERT) for showcasing and disseminating all educational e-resources including textbooks, audio, video, periodicals and a variety of other print and non-print materials through a website and a mobile app. The platform addresses the dual challenge of reaching out to a diverse clientele and bridging the digital divide (geographical, socio-cultural and linguistic), offering comparable quality of e-contents and ensuring its free access at any time and in any place. All the concerned stakeholders such as students, teachers, educators and parents can access e-books through multiple technology platforms i.e. mobile phones (Android, iOS and Windows platforms), and tablets (as e-pub) and on the web through laptops and desktops (as flipbooks) (MHRD, 2016).

All the NCERT books have been digitised and uploaded. Currently, the e-contents are available in Hindi, English and Urdu. States/Union Territories (UTs) are being approached to digitise and share all textbooks in Indian languages through this platform, which will be done in a phased manner. The Web portal and Mobile App of e-Pathshala was launched by the Human Resources Minister during the National Conference on ICT in School Education on 7th November, 2015. The e-Pathshala app has the following benefits for the stakeholder:

For Students it provides access to the following:

- digital textbooks (e-textbooks) for all classes
- graded learning materials (Supplementary books)
- Knowing about events
- e-resources (audios, videos, interactives, images, maps, question banks, etc.).

For Teachers it provides access to the following:

- digital textbooks (e-textbooks) for all classes
- teaching instructions and source books
- materials for helping children achieve expected learning outcomes
- periodicals & journals and opportunities to contribute to them
- Policy Documents, Reports of Committees, NCFs, Syllabus and other resources to support children learning
- audios, videos, interactives, images, maps, question banks, etc.

BYJU's—The Learning App

BYJU'S—The Learning App is the popular brand name for Think and Learn Private Ltd., a Bengaluru-based educational technology and online tutoring company. The app serves educational content mainly to school students from classes 4–12 (primary to higher secondary level education). The main focus is on mathematics and science, where the concepts are visually explained and in context, using modern digital animations and moving illustrations all embedded within short videos (15–20 min long). BYJU'S is focused on creating the best and most unique learning journeys for every student. The learning programmes have been developed to address pressing needs like access to high-quality education and teachers, the lack of personalisation in a one size fits all classroom and most importantly, that learning is driven by the fear of exams, and the not the love for learning. BYJU'S—The Learning App makes use of original content, rich animations, interactive simulations and engaging video lessons from India's best teachers. Delivering world-class learning experience, BYJU'S is making learning contextual and visual, and not just theoretical. The unique combination of media, technology and content has helped create a holistic learning experience for students. For example - The use of real-life teachers with technology as an enabler makes the delivery of complex concepts very easy, effective and engaging. Teachers are crucial to keep students engaged through the program/video lesson and give them *someone who they can relate to*, and *someone who can explain the concepts* to them in a fun, simple and engaging way. This also solves the problem of access to quality teachers in a one-on-one format.

The app has also been designed to adapt to the unique learning style of every student, with regards the pace, size and style of their learning. It is made for every student and not for the motivated ones and the high achievers only. Also, one of the key differentiating features of this app is that it always speaks to or targets the end users, that is students, and helps them become better learners. BYJU'S the Learning app aims to be the learning companion of every student across all grades.

Overall, BYJU'S learning program is a complete learning experience that integrates classes from the best teachers (who are empowered by technology-enabled teaching tools) with assessments and assignments that are personalised for every student, along with in-depth analysis and recommendations. Offering an engaging and effective learning experience, the learning program creates personalised learn journeys for individual students based on their proficiency levels and capabilities which helps them learn at their own pace and style.

The basic learning philosophy behind the app is (a) Watch Video Lessons (b) Test and Analyse your performance and (c) Personalise learning.

Eckovation

The Eckovation App connects students, educators, peers, corporations and workers to enable dissemination of knowledge and information, thereby making quality education and skill development accessible for students and workers across the country. The platform is a confluence point of various ideas from all the stakeholders involved in the teaching and attainment of knowledge process. The app promotes the concept of collaborative education which involves the interplay of all the stakeholders and strives to make a lasting impact in the lives of the students. The app caters to the learning needs of students at the middle and secondary level and provides content based on the curriculum of the National Council of Educational Research and Training (NCERT), especially in the subjects of Science, Mathematics and Social Sciences. Students can also benefit from the test preparation feature of the app which helps them to train for various preparatory exams in science and engineering along with making available content material for various engineering and computer science programmes such as Artificial intelligence, Robotics, Machine Learning etc. The app helps in learning critically important concepts in science and mathematics through a multimedia-based presentation delivered by an experienced teacher or in animated form.

Meritnation

Meritnation is one of India's largest online learning portals for school children who are harnessing the power of mobile learning platforms by offering mobile apps for students. They cater to the learning needs of school students from grades 1–12 across leading educational boards in India. The app is based on the principle that the learning needs of every student is unique with their own learning style, interest, understanding and past academic history, which is the key to making every student successful. Meritnation believes that with technology they can transcend traditional boundaries and truly enable customised self-paced learning. Their experienced team of educationists and technologists are passionate about changing the status quo and challenging one another continuously, thereby providing a seamless product that empowers tomorrow's leaders. The app introduces numerous innovations in the areas of content, delivery formats, reports, assessments and gamification techniques especially in science and mathematics and provides learning resources. The students get access to real interactive classroom experiences with video, quizzes and more, sessions on clearing of doubts using a 'chat' with a teacher, rich learning experience via multimedia content and assignments and homework after every class to ensure complete mastery of the topic.

Tinkering Laboratories

Tinkering is an interesting way to understand the world and its problems before finding potential solutions. As children, we tinker with things—pulling them apart to see how they work or putting things together to see what happens. Becoming an inventor is not an overnight process. It often takes years of tinkering before you can invent something meaningful and useful. Skill and knowledge are important components of progress and prosperity of a society—skill to make things which could be used to enhance knowledge. This is the classic difference between science and engineering. To understand scientific principles and to further the understanding of science, you are often required to design and build an experiment. Thus, having skills to make things would be useful in learning science. Science is an enquiry about 'why?' Engineering, on the other hand, is about manipulating the natural and man-made resources to improve quality of life, ease of living, providing food, shelter, medical care to all humans with minimum disturbance to the natural world. Engineering is about 'how?' Science and engineering are two sides of a coin and one cannot expect to pursue one without the support of the other (Gadre, 2018).

The Tinkering Laboratory concept is new in India and very few schools have established such laboratories for promoting STEM education. The major thrust for the introduction of tinkering laboratories came when the Government of India started the *Atal Tinkering Labs* (ATL) project and provided grants to schools for setting up such labs. ATL is an approach of the Central government of India to create an environment that fosters scientific temperament, innovation, and creativity amongst Indian students. ATL labs have the possibility for students to learn essential STEM skills which will help them in developing their professional and personal skills.

The Government of India set up the Atal Innovation Mission (AIM) at Niti Aayog. AIM is also envisaged as an umbrella innovation organisation that would play an instrumental role in alignment of innovation policies between central, state and sectoral innovation schemes, incentivising the establishment and promotion of an ecosystem of innovation and entrepreneurship at various levels—higher secondary schools, science, engineering and higher academic institutions, and SME/MSME industry, corporate and NGO levels. Realising the need to create scientific temper and cultivate the spirit of curiosity and innovation among young minds, AIM proposes to support the establishment of a network of Atal Tinkering Laboratories (ATL). ATL is a workspace where young minds can give shape to their ideas through a hands-on do-it-yourself mode while learning innovation skills. The vision is to cultivate one million children in India as Neoteric Innovators. The objective of this scheme is to foster curiosity, creativity, and imagination in young minds and inculcate skills such as design mindset, computational thinking, adaptive learning, and physical computing. Young children will get a chance to work with tools and equipment to understand the what, how and why aspects of STEM. ATL would contain educational "do it yourself" kits and equipment related to science, electronics, robotics, open source microcontroller boards, sensors and 3D printers (Niti Aayog, 2017).

An ATL consists of materials and tools to make tinkering possible. In this age, tinkering is heavily influenced by embedded computers—computers that are embedded inside gadgets, everyday objects, instruments, cars, and toys, to help make such devices perform better. Apart from various types of embedded computers, the ATL inventory includes mechanical, electrical and electronic components and various types of sensors. Further, it includes fabrication tools including a 3D printer to help put together whatever gadget, invention or prototype the school students may have in mind.

Given that an ATL consists of some great tools and components, these resources could be used to further science as well as engineering in a school environment. Experiments could be built to enhance learning which would further students' understanding of science and students could learn to create engineering solutions to the nation's problems. Due to the limited scientific knowledge that students normally possess at a school level (because they are still in formative stages), expectations to create engineering solutions should be kept to a minimum. That said, one need not rule out the development of useful engineering solutions at school level.

Conclusion

With the advent of technology in schools and especially in STEM/science education, it is only a matter of time that we will find most of the schools across India harnessing the full potential of technology for teaching STEM subjects. It has been consistently shown through various research studies that using technology to teach and learn science has helped improve students' outcomes, whether it is their achievement, their attitudes towards the subject or academic efficacy. Gone are the days of traditional blackboard education. Now is the age of smart classes, which allows educators to impart education using PowerPoint presentations, audio sessions, and video screenings and through 3D digital animations. The use of digital tools of instruction brings an interactive environment into learning. It is in a smart class where better transparency is established between the educators and students. Since learning is linked to photos, maps, images and animated videos, a student will be able to establish a stronger connection with the educator. The teachers will be enthused to share their thoughts freely in class, expressing them through writing and drawing. It is not an exaggeration to claim that a lot can happen in a smart class. In a class enabled by smart technology, active students glued to various digital gadgets in their pursuit of holistic education are conspicuous. The classrooms are buzzing with inquisitive chatter and interactions between student groups. This inquisitive chatter is what makes learning fun for students. Similarly, the concept of mobile learning and tinkering laboratories are also catching up in Indian schools and with the government focus on skill development, improving science education by promoting STEM subjects has come to the forefront. Through such developments, the students will be able to take advantage of learning apps, improve their social interactions, build engagement, be flexible and learn at their own pace and in their own time.

Given the enthusiasm for the newest electronic devices in the culture at large, schools have an understandable tendency to see cutting-edge technologies as central to solving educational problems. The teacher must stay focused on the underlying goals of the classroom and of each discipline and evaluate each tool in light of those goals. While iPads and other devices will certainly find a use in science education, educational researchers must make an ongoing effort to understand how and when they may be used for the promotion of scientific practices, and when they should be set aside in favour of other approaches (Wilson, Goodman, Bradbury, & Gross, 2013). Ultimately, an educator's thinking about the use of any technology in science classrooms must not be shaped by the production and availability of particular devices but by a progressive vision of science education, in which students create meaning from interactions with the real world and each other, engaging technology as a tool, where appropriate to that task.

References

Badia, A., Meneses, J., & Sigales, C. (2013). Teachers' perceptions of factors affecting the educational use of ICT in technology-rich classrooms. *Electronic Journal of Research in Educational Psychology, 11*(3), 787–808.

Bitter, G., & Pierson, M. (2002). *Using technology in the classroom* (5th ed.). Boston, MA: Allyn and Bacon.

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). *The BSCS 5E instructional model: Origins and effectiveness* (Vol. 5, pp. 88–98). Colorado Springs, Co: BSCS.

DeCoito, I., & Richardson, T. (2018). Teachers and technology: Present practice and future directions. *Contemporary Issues in Technology and Teacher Education*, *18*(2). Retrieved from http://www.citejournal.org/volume-18/issue-2-18/science/teachers-and-technology-present-practice-and-future-directions.

Eckovation. (n.d.). *A social learning platform: Making quality education available to all.* Retrieved July 10, 2018, from https://www.eckovation.com/about.html.

Ediger, M., & Rao, B. (1996). *Science curriculum*. New Delhi, India: Discovery Publishing House.

Gadre, D.V. (2018). *Path-breaking Atal Tinkering Labs: Why it is time for course correction*. Retrieved Mayhttps://swarajyamag.com/ideas/path-breaking-atal-tinkering-labs-why-it-is-time-for-course-correction.

Meritnation. (n.d.). *Meritnation.com-School made easy.* Retrieved July 11, 2018, from https://www.meritnation.com/about-us/index.

Ministry of Human Resource Development. (2016). *E-Pathshala*. New Delhi: Government of India.

Minshew, L., & Anderson, J. (2015). Teacher self-efficacy in 1:1 iPad integration in middle school science and math classrooms. *Contemporary Issues in Technology and Teacher Education, 15*(3), 334–367.

Montrieux, H., Vanderlinde, R., Schellens, T., & De Marez, L. (2015). Teaching and learning with mobile technology: A qualitative explorative study about the introduction of tablet devices in secondary education. *PLoS ONE, 10*(12), e0144008. https://doi.org/10.1371/journal.pone.0144008.

Niti Aayog. (2017). *Atal Tinkering Laboratories*. Retrieved May 7, from http://niti.gov.in/content/atal-tinkering-laboratories.

Strommen, E., & Lincoln, B. (1992). Constructivism, technology, and the future of classroom learning. *Education and Urban Society, 24*(4), 466–476.

West, D. M. (2015). *Connected learning: How mobile technology can improve education*. Retrieved May 8, from https://www.brookings.edu/research/connected-learning-how-mobile-technology-can-improve-education/.

Wilson, R., Goodman, J., Bradbury, L. & Gross, L. (2013). Exploring the use of iPads to investigate forces and motion in an elementary science methods course. *Contemporary Issues in Technology and Teacher Education, 13*(2). Retrieved from http://www.citejournal.org/volume-13/issue-2-13/science/exploring-the-use-of-ipads-to-investigate-forces-and-motion-in-an-elementary-science-methods-course.