Design and Technology: An Emergent School Subject

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Abstract

How can one reconcile Gandhiji's self-reliance principles envisioned in his Buniyadi Taleem (Basic Education) and Nayee Taleem (New Education) and iconised by the disciplined operation of a charkha, with Tagore's dream of unleashing the nation's individual and social creativity embodied in his conceptualisation of Shantiniketan? The answer seems to suggest itself: a suitable education in design and technology. Technology and Design are organically linked. The latter stands for innovation and creativity, while the former is the very foundation of self-reliance.

The most compelling arguments for including Design and Technology (D&T) as part of school education arise from what it means to be human. I will argue for the inclusion of D&T as part of Indian school education in terms of its cultural and cognitive relevance. I will show that design and its practices are not subsumed either within the arts or the science school subjects. On the other hand, the cognitive benefits of designing are on par with and complimentary to the knowledge and skills gained from engaging in the sciences, and the humanities, including the arts and literature. Studies have been carried out at HBCSE on design and cognition as well as on the collaborative and communicative modes of working on D&T units. I will draw upon these studies carried out in different Indian school settings, and related studies from elsewhere, to illustrate how learning to design and make at the school level can empower students.

I will touch upon the need for a distinct model of D&T education for Indian schools to enable equitable participation of students from diverse backgrounds, and propose the salient features of a possible D&T curriculum. I will briefly discuss the challenges of D&T education curriculum for Indian schools. Arguing that D&T is a vehicle for multiple modes of expression, creativity and design, I will discuss how Indian multicultural classrooms can benefit from D&T activities centred on communication and collaboration.

I. Introduction: Gurudev and the Mahatma

> "Our education has got to be revolutionised. The brain must be educated through the hand. If I were a poet, I could write poetry on the possibilities of the five fingers... Those who do not train their hands, who go through the ordinary rut of education, lack 'music' in their life. All their faculties are not trained..." *Mahatma Gandhi to teachers,18-2-'39* (Gandhi, 1994)

Imagine that you are visiting an Indian metropolis and find it well laid-out. Everything around you seems to have been *designed* to work: bus routes and stops, trains, stations, airports, all artefacts and organisations, schools, and curricula. You talk to a spectrum of people from different walks of life and learn that the planning has been participatory and carried out with insight. This indicates in all probability that the general education of all people in the metropolis included courses on design and technology, which was then extended within vocational education. This situation – some may call it utopia - in India, unfortunately, is a long way coming.

The plea for inclusion of technology related aspects in general education was made about a century ago by two of the leading educational philosophers of modern India: Mohandas Karamchand Gandhi and Rabindranath Tagore, known respectively as Mahatma and Gurudev. It was Tagore, who first referred to Gandhi as Mahatma (the Sage) in 1915. Gandhi in turn gave Tagore the sobriquet of Gurudev (the great teacher) referring not just to his initiatives in building a model educational institution, Shantiniketan, but indicating that he was teacher to the whole world. Gandhi in his Buniyadi Taleem (Basic Education) and later in Nayee Taleem (New Education), addressed education of students in all subjects through productive engagement in crafts in general, and specifically, through spinning and weaving.

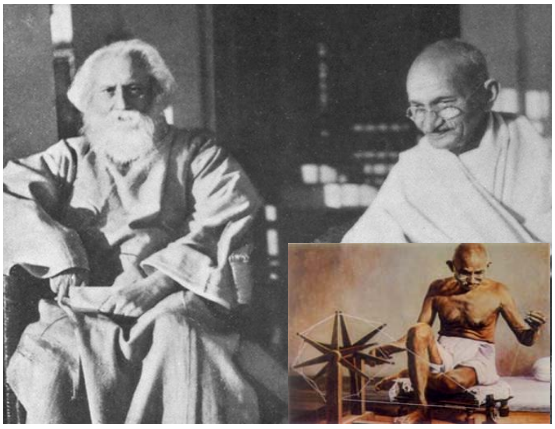
The Wardha Educational Conference held in October 1937 under Gandhi's leadership passed a resolution to provide free and compulsory education to every child of 7 to 14 years of age. The medium of instruction would be the mother tongue, the process of education throughout this period would centre around some form of manual productive work. All the students' abilities developed would be integrally related to the central handicraft chosen, with due regard to the environment of the child. This system of education would gradually be able to cover the remuneration of the teachers. Gandhi elaborated this idea in his letter to Narandas Gandhi on August 10, 1937 (Gandhi, 1994).

Gandhi's model was based on his perceived urgent need at the time to provide economically productive engagement to the majority of starving villagers, while upholding dignity of labour and local self-sufficiency. Though this inspired some of the post-independent educational programmes, in its original form it was perceived as impractical. The Kothari Commission recommendations that resulted in the National Policy on Education in 1968 (GOI, 1968) ended up vocationalising general education, while making vocational education too generic and irrelevant for employment. The education bore no resemblance whatsoever to the Gandhian model of holistic education through productive engagement in crafts. The Wardha model had been completely derailed. (NFG-W&E, 2007)

The main problems in applying the model nationwide came from its impracticality at two levels. Neither the educationists nor the parents were willing to commit to the economic sustainability envisaged for craft teaching through local generation of funds by selling the products made by students. Another, and a major stumbling block was the mastery over subjects as well as crafts required of teachers. Where could such teachers be found? How could they be trained in the large numbers needed in a short time for an ever increasing population of students entering school? Besides, the geographic and cultural diversity in the country required flexibility in the choice of craft taught at school level. While Gandhi himself had built in these flexibilities, there were no guidelines for reaching equitable standards of education through different crafts and their traditions.

The quintessential poet philosopher, Tagore had a comprehensive educational programme, including intellectual development as well as developing a student’s aesthetic nature and creativity. The quest for knowledge and physical activity in an agreeable environment were integral parts of the process. Freedom and creativity are linked in Tagore’s thought, one conditioning the other. A fundamental area of instruction at Sri Niketan, a school that he founded, was handicrafts; it was compulsory for all students to learn a trade. Sri Niketan aimed at combining work with joy. His activity-oriented school for village children appears to have inspired Gandhi’s ideas on basic education. Tagore’s influence can also be seen in the report of the Kothari Commission on Education in India (GOI, 1968).

Figure 1: Gurudev (left) and Mahatma argued over the latter's advocacy of charkha use (inset) for India's freedom.



Tagore objected to the turning of the charkha as a form of ritual. According to Tagore, "... a man can be stunted by big machines, the danger of his being stunted by small machines must not be lost sight of" (Prabhu and Kelekar, 1961, page 65) for, "the performance of petty routine duties... imparts skills to the limbs of the man who is a bondsman, whose labour is drudgery; but it kills the mind of a man who is a doer, whose work is creation" (page 85) "...And further by doing the same thing day after day mechanical skill may be acquired; but the mind, like a mill turning bullock will be kept going round and round a narrow range of habit" (page 91). There were several debates on education, specially on the advocacy of the *charkha* between the poet and the sage (Giri, 2002).

The next section introduces design and technology education as a reconciliation between the visions of Gandhi and Tagore. The following section addresses the cultural relevance of technology. Sections IV to VII discuss design as an activity and its educational features. Design is a part of engineering or technology, which are perceived by some to have important educational differences. Technology is considered the more generic of the two. Aspects of cognition in design as distinct from the sciences, evidences of the multimodal nature of design and technology communications and the role of collaborations in design are all used to justify treating design as a distinct domain of human endeavour and valuable for education. Section VIII is a brief account of the findings from the research done at HBCSE on design and technology education. Section IX argues for a space for design and technology education within general education. The next section raises issues of existing Indian educational context: a large and diverse potentially creative human resource trapped by a constraining curriculum. The section proposes a model of design and technology education in India, and addresses issues of assessment and teacher development. The paper concludes with a global perspective and hopes for the introduction of a technology education curriculum in Indian schools.

II. Reconciling skill learning and creativity

Both creativity and self-reliance have been used to justify the content of school education. Self-reliance at the individual and national levels have influenced content in the science subjects, and motivated the introduction of work education and other vocational subjects in general education. While science is considered an important subject, vocationalisation has failed to find favour among students and parents. Creativity is often associated with the arts, while innovation has been completely sidelined, or left to an elite in higher education. School students are given scant opportunities for design or technological innovation. Schools teach not technology, but about technology; that too as application of scientific principles rather than as an endeavour in its own right. Students rarely, if ever, engage with technology.

Perhaps to make amends for the lack of hands-on activities in school science, National Children's Science Congress (NCSC), initiated in 1993, provides the children of 10 to 17 years from all over the country an opportunity to make projects based on different themes each year. Selected from district and state level competitions, about 500 children take part at the national level in the annual five day activities in December. Only about a third of the schools in most States and a small fraction of the students of these schools participate in these fairs. The large number of potential innovators in the country do not have access to the knowledge and skills that aid innovation. The lack of opportunities in school curriculum for creativity and innovation is glaring in the light of a large proportion of the country's school student population of about 300 million dropping out well before Class X. Only a small fraction of those who pass out from school qualify to learn engineering, design or technology at the tertiary level. This situation is reflected in international reports on the country being dependent on adapting technology and rated low on significant technological innovations (UNESCO, 1998). On the other hand, the history of civilizations of the Indian subcontinent is notable for technological innovations.

In this context, how can one reconcile Gandhi's self-reliance principles envisioned in his educational model and iconised by the charkha, with Tagore's dream of unleashing the nation's individual and social creativity embodied in his conceptualisation of a school? General education for all students in design and technology seems to be the answer. Design and technology are organically linked. The former stands for innovation and creativity, while the latter is the very foundation of self-reliance, an aspect that India values, and one that has guided the country's science and technology policy decisions for decades.

III. Technology and culture

Technology is a social endeavour, being inspired by human needs and owing its existence to the perceived fulfillment of such needs. Hence it is embodied in culture: in the artefacts as well as in the languages and actions that have evolved around them. From pre-history to the Space Age and beyond, all human settlements have “toyed” with technology. History of civilisations is replete with the technological achievements of human communities. The growing needs of humans and their quest for survival have certainly spurred the search for better ways of satisfying them, but so has basic human curiosity for new knowledge. Since the agricultural revolution over 10,000 years ago, humans have evolved culturally, and along with their cultures, have evolved their technologies (DeGregori, 1989). Architecture and town planning, metallurgy and sophisticated surgical tools, innovations in agricultural practices and implements, and several others indicate a rich heritage of technology in India (Kumar and Mahurkar, 2002).

Any technological activity is task-centred and goal-directed and hence purposeful and focused. Design and technology involves making decisions, like which product or system will serve the purpose, how it will be made, who will make it, what materials will be used to make it, who it will serve best, what effect it will have on social and environmental systems, and so on. Development of technological competence involves continued use in activity, especially in “authentic” or “real” situations. Solving problems set in the real world initiates a variety of cognitive processes, including reasoning about purposes in relation to the resources and tools the situation affords (constraints). Cognitive content as well as processes depend on language, artefacts and tools of the culture (Nisbett et al, 2001). Language production, meaning making, discourse, tool use and tool making are all best understood as a dynamic interplay between individuals and society at various levels of interaction.

While the raison d’être of technology is to create purposeful change in the “made” world, one may well ask, echoing Marxist ideologies, “whose purpose” it is intended to serve. From a social constructivist paradigm of technology, Langdon Winner (Winner, 2002) argues that technologies have inherent political implications, and may be strongly compatible with specific social orders. Nuclear technologies tend to be centralised and authoritarian rather than egalitarian. A flyover may limit access to a beach to certain socio-economic groups. According to Winner, the political consequences of such technologies can be traced to their designs. Greatest latitude of choice exists at the very beginning, and this flexibility vanishes once initial commitments are made.

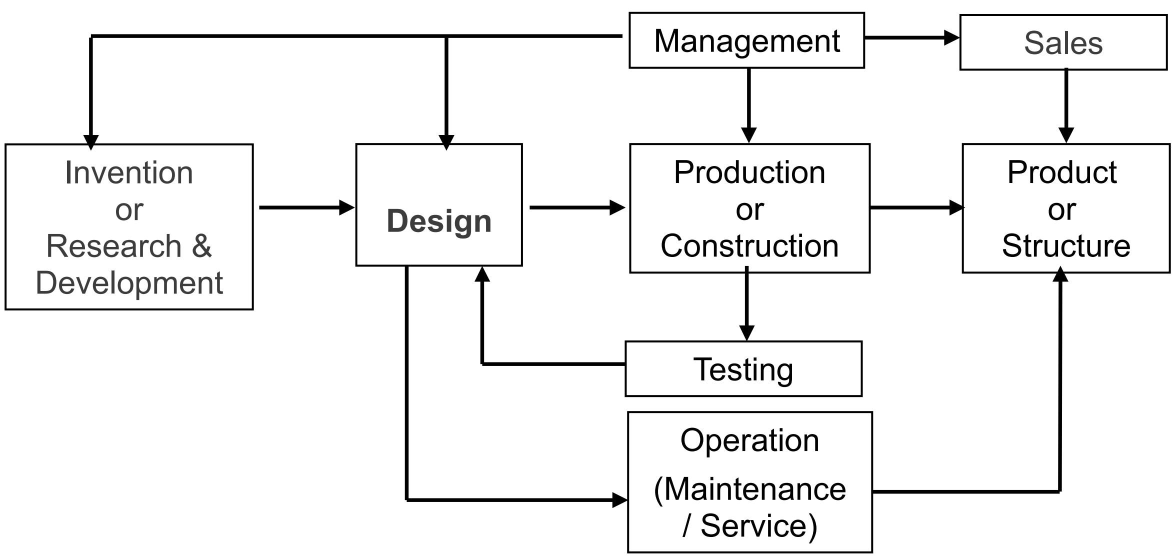
Clearly then, it is essential for communities to negotiate the goals of technological activities to better serve their lives and sustenance. In all innovations, there can be winners and losers. The physical environment and its resources may be compromised. Within the technological activities of their community, it is important that all people learn to integrate values that can sustain natural resources and ensure socio-cultural equity (Natarajan, 2004). The survival of cultures is evidence that all cultures have the capability to visualise and redesign their environment in harmonious and aesthetic ways, or for purely functional purposes.

IV. Engineering, technology and D&T education

Technology is a basic human capability, much like language. It is the use of knowledge, skills, materials, tools and systems, as well as the creative process and values and judgements, to improve the quality of human lives. It uses science as well as other organised knowledge to achieve practical tasks. Engineering too uses a core knowledge of concepts, skills and procedures. However, engineering concepts are predominantly from science and mathematics. In the context of education, technology is generic, while engineering, is vocation specific with fields like mechanical, electrical, civil, etc. Activities in both technology and engineering may be broadly viewed as having four, not necessarily distinct, stages: invention or research, design, construction or prototype making and final production of product(s) (Mitcham, 1994). This is schematically shown in Figure 2. While engineering emphasises the first three, technology focuses on the latter three.

Design, a core activity in both technology and engineering, connects the initial thought to the final product, whether prototype or mass produced. Design is "reified thought": it is through design that artefacts and their organisations come into being and evolve. Design can be understood both as a noun and a verb. Design, in a broad sense, is the bundle of techniques, skills and approaches that can be used to determine and make sense of the future character of the world of buildings, places, images and products. Handling change in a purposeful way is one of the main characteristics of design activity. Design is also the field in which handling of change and its outcomes are set.

Figure 2: A possible model of engineering and technology activities from Mitcham (1994) p 216



Emphasis on design within technology education affords a space for critical debate about social, ethical and environmental dimensions. For individual and social survival, it is important to foresee the qualitative results of technological change. Consumers or users of design products and activities, when equipped with a broad range of skills and understanding in the realm of Design and Technology (**D&T**), can take better control of their own environment.

V. Design and cognition

Science and design address distinct spheres of human knowledge, use different cognitive tools of study, engage in diverse activities. The natural sciences are concerned with how things are, the nature of what exists. Scientific activity is a process of pattern recognition. Design is concerned with how things ought to be. It is about inventing things of value which do not yet exist, a case of pattern synthesis. Science is analytic; design is constructive. (Gregory, 1966)

Design is about making things work better. It may be about designing fresh smelling textiles, or fashionable, functional and inexpensive clothes. It may be about making your locality beautiful and convenient, making an easily readable tour map that showcases your institution or city, or planning an emergency response system. Design is also about seeing the world in special ways; in creative ways; in designerly ways (Cross, 2007).

A central feature of design activity is the quick generation of a satisfactory solution, rather than any prolonged analysis of the problem. The scientist suspends judgements and decisions about the solution until the problem is known. In the case of design problems, all the necessary information is never available to the problem-solver: design problems are characteristically ill-defined or ill-structured. The solution of such problems call for and sustain development in multiple modes of cognition. Designers use 'codes' that translate abstract requirements into concrete objects. They use these codes to both 'read' and 'write' in 'object languages'. The concrete or iconic mode of cognition is an innate human ability. Proponents of situated cognition and followers of Bruner's ideas (Lave and Wenger, 1991) suggest that cognitive development is a continuous process of interaction between different modes of cognition, concrete/ iconic and formal/ symbolic, all of which can be developed to high levels. These are not merely a characteristic of a stage of development. The need for the development of such modes of cognition through general education is addressed in Section IX.

VI. Multimodal communication in D&T

A concrete language is essential to technological innovations. As quoted in Kimbell et al (1996), there is a critical and recursive (iterative) relationship between expression of ideas and the development of ideas among school students. "... the act of expression pushes ideas forward. By the same token, the additional clarity that this throws on the idea enables the originator to think more deeply about it, which further extends the possibilities in the idea. Concrete expression (by whatever means) is therefore not merely something that allows to see the designer's ideas, it is something without which the designer is unable to be clear what the ideas are." (p 23-24)

Design and technology activities provide the discourse space and cultural environment that support the use and learning of technology-specific language. Activities in this domain involve description through technical terms, using images and symbols, through sketching, technical drawing, diagrams and photographs. Signs and symbols are used for representing an idea, modifying it and communicating with peers. In design and technology activities, students can be encouraged to discuss materials, shapes and sizes and their affordances, read and write about technological artefacts. Communicating about design needs nonverbal modes, graphic images like drawings, diagrams and sketches as well as the use of mental imagery.

Solomon and Hall (1996) have emphasized the purpose and importance of language in technology education: 'Language is vital for almost all learning, for describing shapes, anchoring concepts, and making the tacit articulated…..' (p. 275). External representations play a special role in internal cognition (Langer, 1962 in Kimbell et al, 1996; Vygotsky, 1966). The history of engineering drawings demonstrates that the modelling methods available to designers affect the potential content of their thoughts (Baynes 1992). Yet, communication remains one of the most neglected components of technology education.

Teaching design and technology to primary and pre-school students can help to promote creative, critical and playful thinking. It helps children internalise and develop their imagination using tools of thought, which evolve as they are used in playful, innovative ways (Parker-Rees, 1997; Senesi, 1998, 1998a, 2000, 2000a). Evidences of design thinking have been noted among children between 3 and 9 years of age (Senesi, 1999; Senesi, 2000; Fleer, 2000, Hope, 2000) as well as among 11 to 14 years old middle school students (MacDonald and Gustafson, 2004, Khunyakari, 2008).

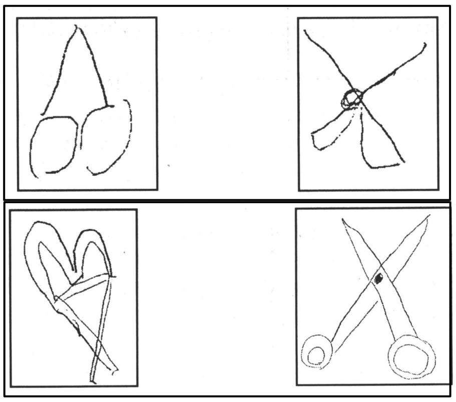


Figure 3: Drawings made by 5 year old children before (left) and after a short study of scissors (Senesi, 2000).

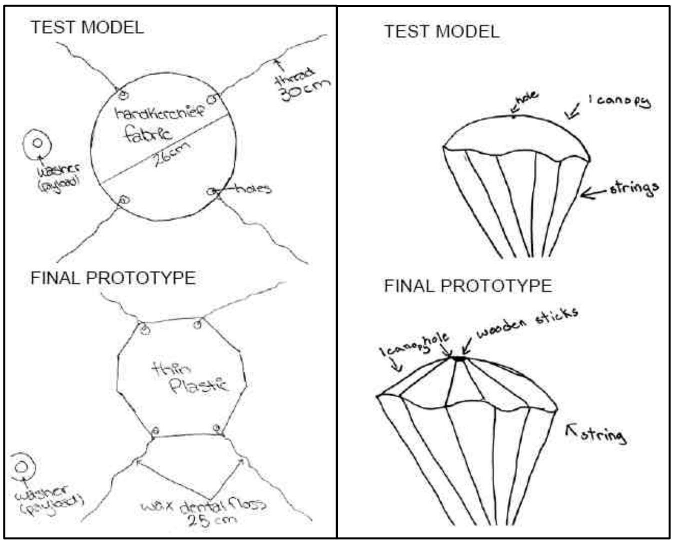


Figure 4: Drawings of a Grade 6 student before and after parachute making activity. (MacDonald & Gustafson, 2004)

In one study by Senesi (2000), after making artefacts like spinning tops, pop-up cards and cardboard cars, French pre-primary rural school children (aged 3-6 years) talked less about magical and functional aspects of the artefacts and more about their structural and making aspects than they did before making. In another study (Leonard, 1997 in Senesi, 2000), one of Senesi's students found that 5 year old children made more accurate drawings of scissors after using it reflectively than they did before (Figure 3).

In another study among Grade 6 students in the USA (MacDonald and Gustafson, 2004), students' sketches of parachutes drawn after making the artefact more accurately represented their parachutes (Figure 4). The studies revealed that after the interaction with the tools and materials, there was significant progress in students' concepts and knowledge of the artefacts and of tool use.

VII. Collaboration in D&T education

For Bruner (1996) and Rogoff (1998), classrooms are communities of mutual learners, where understanding is fostered through collaboration and discussion. In any classroom, teachers and students comprise a community of learners, in which knowledge is shared and co-constructed. Cooperative learning stresses the product of working in groups. Its proponents claim that 'the active exchange of ideas within small groups not only increases interest among the participants but also promotes critical thinking' (Gokhale, 1995, p. 22). According to Roschelle and Teasley (1995, p.70), collaboration refers to a 'coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem.' Hennessey and Murphy (1999, p. 27) feel that "collaboration is an important aspect of problem solving, which enhances learning (including planning) by making thinking more explicit and accessible and (by) enabling pupils to construct joint understanding of tasks and solutions."

Collaborative learning is both about collaborating to learn, and learning to collaborate (Collazos et al., 2002). Rowell (2004) recommends that skills needed for collaboration have to be nurtured from childhood. Socio-cultural settings influence perception of teamwork, the collaboration processes, and the transition from observing to doing a task. Besides, knowledge gained through technology activities is that of technology as social practice and is mediated by the use of tools, resources and language within the community. This happens in appropriately structured classroom activities as participants articulate strategies for achieving solutions to problems and evaluate their artefacts. Classroom practices reflect the collaborative endeavour among designers, makers and users (Kolodner and Nagel, 1999).

Barbieri and Light (1992) studied 11-12 year old children working either alone or in groups on a computer task. Their interactions were videotaped, analyzed and the working of groups were compared with students working alone on the same task. There were significant differences in planning and negotiation in the two cases. Children who worked in pairs asked questions and gave explanations, which led to better organization of knowledge. Teasley (1995) has also reported that students working in groups learned better than students working alone.

Collaborative activities have several cognitive advantages, whether seen from the Piagetian viewpoint or the Vygotskian ones. In the socio-cultural perspective, the study of cognitive development involves different planes of observation and analysis: the individual, interpersonal and institutional (Rogoff, 1998). The social and material contexts are integral to the shared cognition among collaborating people.

Figure 5: Collaboration while making a windmill model may be analysed on the plane of (a) an individual student (constructivist view), (b) interpersonal interactions (social interactionist view), or (c) the institution, including individuals, their socio-cultural and material contexts.

Educationists as well as employers have emphasized the need to train students in the skills of communication, effective presentation, negotiation and teamwork, as part of general education (Thangamuthu, 2007, Karnik, 2007). However, there is a mismatch between what students learn at school and college, and the skills and competencies needed in work places. The competitive environment of the Indian classroom, often having a greater than optimal number of students and taught by the transmission/ lecturing mode, leaves little room for collaborative interactions among students.

VIII The D&T Education Project at HBCSE

In a recent article Ken Baynes (2006) opines that there are two apparently contradictory views of design and designing. In one view, designing and understanding design is a highly specialist, complex and esoteric thing, which people can only do after a long apprenticeship. Another holds that design ability - the ability to design and to understand design - is, like language ability, something that everyone possesses at least to some degree. He further suggests that on the basis of our understanding in cognitive science, the two views are complementary: the complex skills of design professionals are the result of development of abilities that all people possess.

The Design and Technology Education Project initiated at the Homi Bhabha Centre for Science Education (HBCSE) in 2000 explicitly holds the second broader view. A model for transaction of D&T activities in the classroom has been developed (Figure 6), as a step towards a possible school level D&T education curriculum (Choksi et al, 2006). This "collaboration and communication centred D&T education" model is inspired by the UK curricular model - the Design-Make-Appraise of APU. The approach of the project shifts the emphasis from the dominant global view of technology education emphasising use of digital technologies, and the local view of technology as merely applied science, to a collaborative engagement of student teams in designing, making and evaluation of need-based artefacts and systems.

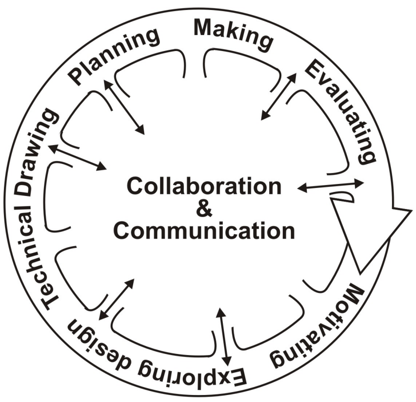


Figure 6: A model of D&T education centred on collaboration and communication. (Choksi et al, 2006)

Three D&T education units were developed through classroom trials: bag-making, windmill model making, and puppet making and putting up a puppet show. The trials involved students in Class 6 and 7 (age 11 to 13 years) from three school settings: English medium urban school, Marathi medium urban school and Marathi medium tribal school (*Ashramshaala*). Each unit, conducted over 15 hours was set first as a problem in the students' context. Investigation, the beginning of the sequence of tasks, provided opportunities for students to talk and write about related artefacts, explore available ones in their homes and in shops, and discuss their structures and functions. Students then explored their own ideas through group discussion and design sketches, used quantitative reasoning skills to depict their design of the artefact and indicated its dimensions. They made measurement and anticipated the making sequences, including work distribution among members of their group.

While they were encouraged to discuss within groups, they also informally communicated with other groups and the researchers. Besides, communication was structured after the design stage and after they had evaluated their made products. Thus activities in each unit were designed to encourage communication and collaboration at various levels. Learning of relevant concepts was integrated with each unit through worksheets and suitable activities. Data was collected during the trials in the form of students' paper-pencil productions of drawings, structured and spontaneous writings, researchers' notes and audio and video recordings. The productions included design exploratory sketches, technical drawings, material lists and procedural maps, worksheets on concepts and evaluation, as well as the final product (Khunyakari et al, 2007; Mehrotra et al 2009; Khunyakari et al, 2007a).

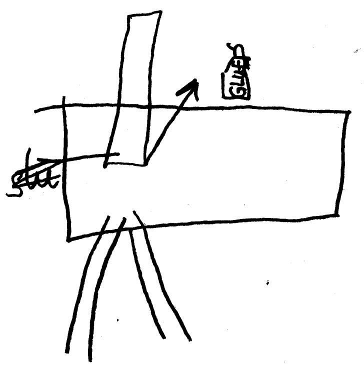


Figure 7: Design exploration of a windmill showing thinking about materials for joints, and an icon for glue.

Evidences of cognition and design thinking

Students' engagements in the D&T tasks in the HBCSE study gave evidences of cognition: in talk, gestures, sketches and models. Examples of students' cognitive activity included the following:

- use of depiction "language" with icons, graphical symbols, labels, annotations (Figure 7)
- design explorations showing design thinking about materials, joints and assemblies (Figure 7)
- quantitative reasoning, estimation strategies, dimensions (Figure 8)
- visual and conceptual analogical reasoning (Figure 9)
- exploration of tools and their reflective use, evolution of skills and procedures in using tools and materials
- design progress within each unit from exploration through technical drawing, procedural map to artefact (Figure 10)
- justification of design and communication of product evaluation

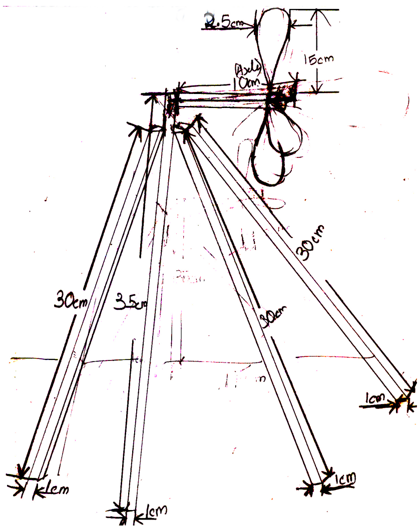


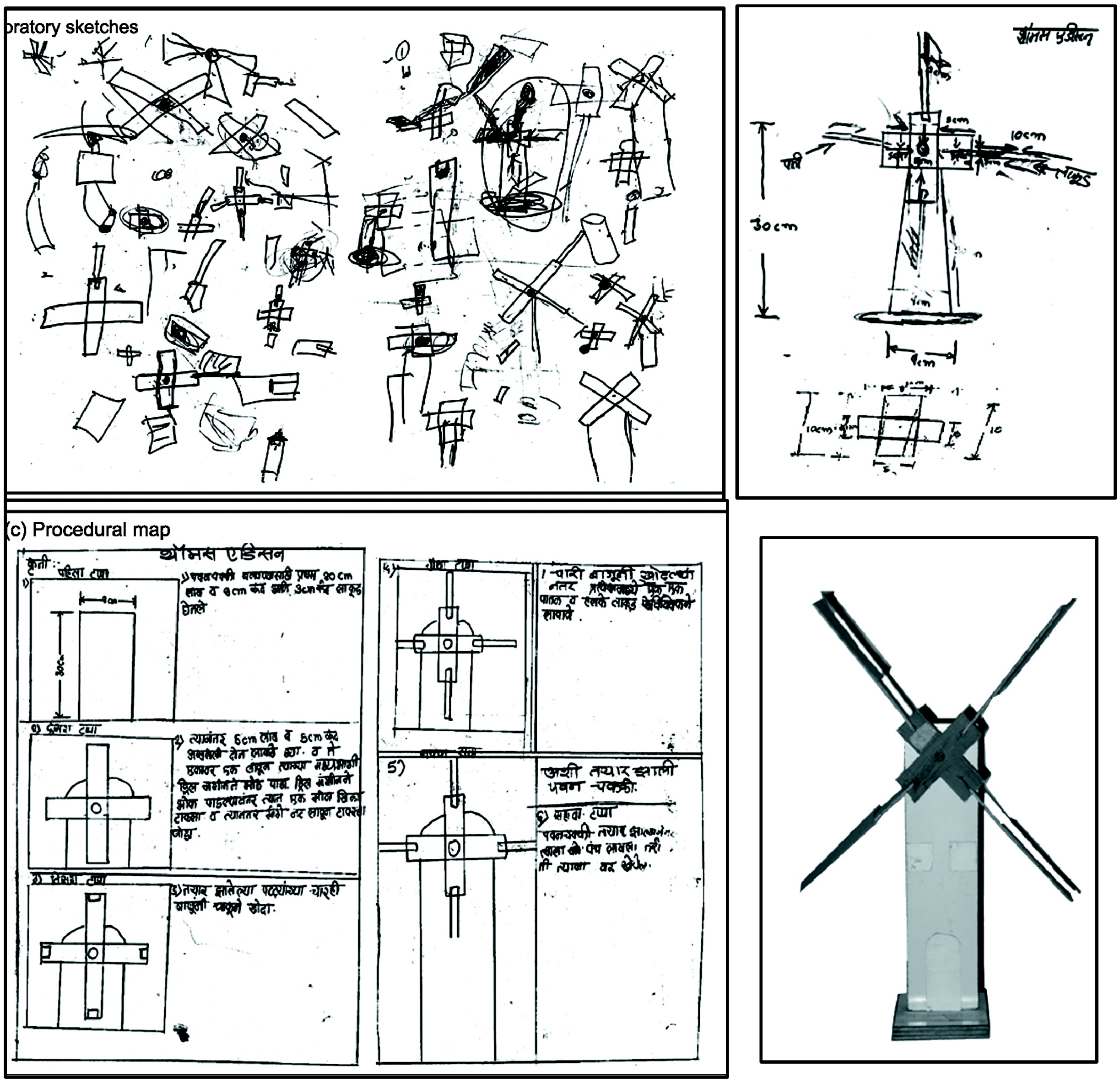
Figure 8: Depiction of measurements in the technical drawing of a windmill

During explorations and beyond, in fact through the designing process, students spontaneously generated icons and other graphical symbols to satisfy their depiction needs (Figure 7). In another research at HBCSE, in which students made a route map based on given verbal directions, 96 students generated 30 different icons to depict the 10 landmarks given in the verbal description (Ara, 2007). Besides, in the same study, students used 8 different graphical symbols for depicting streets. When they were exposed to the conventions of end-lines, leaders and arrows, students used them in all subsequent design drawings (Figure 8).

Designing and making an artefact, whether it is a simple bag, a puppet for a puppet show or a windmill model, requires students to visualize and depict the spatial relations between components and assemblies. It calls for mental transformations (translations and rotations), analogical and functional reasoning (Figure 9). Complex or unfamiliar objects, parts and assemblies place a greater cognitive load on the visualization process than do simpler and familiar objects. Sketches and gestures are known to ease this load. The average number of exploratory sketches per group was more in the structurally less familiar and complex object like a windmill model (17.8) than for either a puppet (5.4) or a bag (3.3). In D&T tasks, skills and tool use procedures are practiced and knowledge applied in authentic problem solving settings.

Figure 9: Conceptual analogical reasoning indicated is by the tripod being adapted for a windmill tower.

Figure 10: Design evolves from exploratory sketches through the final depiction in technical drawing and procedural map for making to the actual making of the windmill model.



Designs evolved from students' explorations to their anticipated plans or procedural maps (Figure 10). Their depiction abilities in technical drawings and procedural maps were also observed to progressively improve with every successive D&T education unit. They made neater, better labeled and annotated technical drawings and procedural maps. Besides, their depictions in the procedural maps increasingly matched the accompanying text, which in turn became more elaborate. Making tested the practicality of students' designs. Problems were encountered and solved through changes in design – material, shapes of parts, reinforcing, etc. Students reflected on redesigning their artefact after making.

Evidences of multiple modes of expression in design contexts

In another study, middle school students had to depict and describe artefacts that included simple pipes and solid cylinders as well as a bicycle, before and after they had handled them (Selvaraj, 2007). In the less authentic context of drawing pipes and cylinders, most students failed to either depict the described object in proportion or label the dimensions given in the text. Besides, handling similar objects of different sizes made little difference to their depictions and descriptions. However, the details of parts, their positions and proportions in the depiction of bicycle improved after handling. It appears that authentic contexts of interaction with objects aided visualization. On the other hand, design contexts, as discussed earlier spontaneously elicited several modes of communication: sketches, writing, a variety of talk and gestures. Besides, there were several levels of communication when students worked in groups on D&T tasks: among members of a group, between groups and between the teacher and the groups or individuals (Mehrotra, 2008). The communication may happen spontaneously (informal) or may be structured as an activity (formal), as seen in the diagram in Figure 11, which reflects the collaborations among individuals and groups.

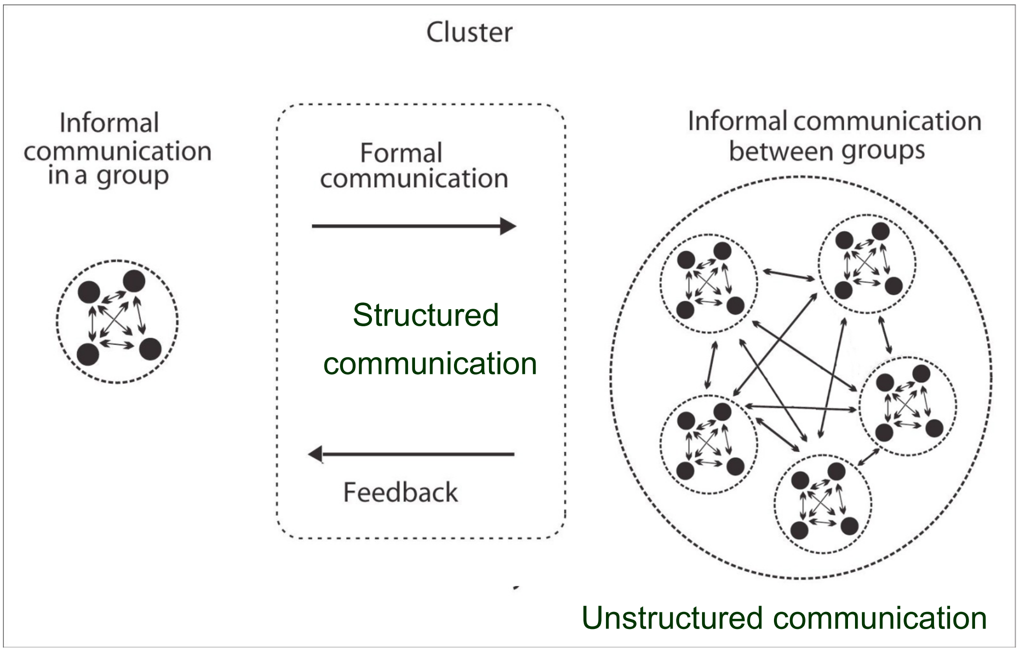


Figure 11: Levels of communication in D&T units, where dots represent students and arrows symbolise interactions (Mehrotra, 2008).

Evidences of collaboration

The design of activities in the trials of the D&T units was conducive for students to collaborate. Levels of communication, relations developed between members and roles played by them within and across groups gave evidences of collaboration. Collaborative completion of design production and shared understanding of the design ideas among group members was typically observed in several groups. Most students did not refer to their group's design productions. Yet there were significant similarities between the design productions and the finished product. It seemed that students knew what they had to do next while making, suggesting that, once explored and conceptualized, the design remained in the shared memory of fellow designers and makers. The design of the units design and group work provided opportunities for collaborative creation of objects and knowledge.

IX. Design and Technology needs a distinct space in general education

In the last few decades, professionals from a widely ranging fields – engineers and technologists to philosophers, designers, educationists and even architects – from several countries around the globe, have made a plea for the inclusion of technology education in some form as part of the general education of all students. One of the foundations of their arguments is that design, which is a core activity of technology, is a basic human capacity (Cross, 2002; Roberts, 1999).

Technology and design are about the human-made world. Design involves modelling, pattern formation and synthesis to serve a human purpose hitherto unmet or inefficiently served. Technology, on the other hand, includes the practical aspect of model making with the aim of efficient production. The values of practicality, ingenuity and a concern for appropriateness thus characterize the discipline of technology and design. Design and technology education bridges the gap between an education in the natural sciences, which is about the natural world with a concern for truth, and an education in the humanities or liberal arts, which is about the human experience with a concern for justice. The sciences and the arts/ humanities study or use the designed world. Science uses artefacts and provides knowledge/ process inputs to design artifacts, while the arts/ humanities study artefacts and utilize the tools of culture, including artefacts. D&T thus forms a distinct domain of study; as distinct as the sciences, the arts and the humanities. Technology and its practices are not subsumed either within the arts or the sciences. Their objects of study, the methodologies they use and the values they uphold are different in some ways. Table 1 is an adaptation of a summary by Nigel Cross (1982) of the differences between the sciences, humanities (and the arts) and design.

Table 1: Comparison of properties of the three broad subject domains of the sciences, humanities and technology.

Property	**Sciences**	**Humanities & Arts**	**Technology & Design**
Is about	Natural world	Human experience	Human-made world
Involves use of	Hypothesis, experiments, classification, analysis...	Analogy, metaphor, criticism, evaluation, etc.	Modelling, pattern formation, synthesis, etc.
Values	Objectivity, rationality, neutrality, concern for **truth**	Subjectivity, imagination, commitment, concern for **justice**	Practicality, ingenuity, empathy, concern for **appropriateness**

A. N. Whitehead (1953) suggests that "There are three main roads along which we can proceed with good hope of advancing towards the best balance of intellect and character: these are the way of literary culture, the way of scientific culture, the way of technical culture. No one of these methods can be exclusively followed without grave loss of intellectual activity and of character." (p 111)

Several educationally important aspects that characterise design thinking have been discussed in the earlier sections, especially Section V and VI. Including the development of psycho-motor skills and practical aspects of technology, there are three main areas of justification for D&T in general education.

First, D&T develops abilities in solving real world problems, which are often ill-defined and provides authentic contexts for constructive thinking, distinct from inductive and deductive reasoning. Second, D&T sustains development in multiple modes of cognition through its contextual use of codes and object languages. An education for the development for constructive thinking while working with designing codes has been for long neglected. This can perhaps, be traced to the dominance of the cultures of the sciences and the humanities, and the dominance of the stage theories of cognitive development. The third justification for D&T in general education comes from its integration of episteme (knowledge), techné (skill), and phronesis (practical wisdom) (Dunne, 1993).

Over and above the verbal, numerical and literary modes of thinking and communicating that most school subjects aim to develop, as discussed in Section VI, D&T develops multiple modes, including nonverbal ones, graphic images like drawings, diagrams and sketches as well as the use of mental imagery. According to French (1979), development of nonverbal thinking is perhaps the principal justification for design in general education: “It is in strengthening and uniting the entire nonverbal education of the child, and in its improvement of the range of acuity of his (sic) thinking, that the prime justification of the teaching of design in schools should be sought, not in preparing for career or leisure, nor in training knowledgeable consumers, valuable as these aspects may be.” The goals of D&T education are thus more fundamental than those of education in the arts or vocational education.

Doing technology entails defining the problem, generating solution strategies (ideas), making models, applying constraints, selecting appropriate model, evaluating (critical thinking) and modifying the model before implementing. Designing happens in real-world contexts, for contemporary purposes, to satisfy demands of real users, and hence takes account of contemporary knowledge, tools, values and aesthetics in a given society. One may argue that the design itself is constrained by the collective knowledge of concepts and skills among the designers. However, the envelope of such knowledge is expanded by the very problem to be solved that demands that designers learn about materials and tools, and acquire the skills and techniques to arrive at a solution that will satisfy the purpose and the user.

D&T education is in contrast to technical or vocational education that is procedural rather than designed and low in academic content. The latter emphasizes skill acquisition by following a given prescription that is required to be guided neither by negotiated nor contemporary needs. It easily becomes obsolete, needing frequent re-skilling. For locally appropriate innovation, D&T education, starting at the school level, must include knowledge, critical thinking about the activity and its consequences, as well as sensitivity to issues of equity and sustainability.

D&T activities in school education need to involve multidisciplinary perspectives, broad based skills, and multiple modes of expression. School education that merely addresses knowledge about technology can stifle innovation. D&T education has a scope wider than either applied science, vocational education or work experience, and it transcends science for its disciplinary grounding.

There can be several facets to technology education at the school level depending on the stakeholders, who support it. As an economic instrument, technology education contributes to national wealth creation. It helps sustainable development by making economic growth compatible with environmental protection. Technology education has hitherto served to enhance the professional image of technology or engineering, improving its standing in society. This has led to a traditional view of technology driven by science, which has been the justification for teaching technology as applied science in Indian schools. But historically, technology has often led science. Science can provide the resources/ means for technological advances. A D&T education needs to include a metaphoric understanding of technological activities for all people, not only for the practitioners and professionals. Hence, it is time that the discipline goes beyond being the exclusive domain of higher education and enters the portals of schools and empowers students from a very young age.

The last few decades have seen a resurgence of interest in technology education around the world. The content, skills, and processes encompassing technology education are all being examined. Common to most curricular proposals is the importance of the design process as inherent to an education in technology (Vries, 2006). Even so, the number of different ways of introducing design in school curricula are as many as there are educational policy makers in the world. They include several country specific approaches and priorities, and are based on individual and cultural understanding of what technology means.

Layton discusses the possible pragmatic goals for choosing to teach technology (Layton, 1994). Some countries like India approach technology as application of science. Some include design for furthering scientific understanding, as does HBCSE's science curriculum. Others, like Israel, include projects in science and technology (S&T), while some like Australia emphasize S&T for environmental sustainability. The curriculum in the USA specifies engineering design and seeks to integrate science, technology, engineering and mathematics (STEM). One of the earliest to implement a D&T curriculum, England has argued for prominence of design in technology education with making (Kimbell et al, 1996) and without making (Barlex and Trebell, 2007). Some countries like New Zealand emphasise technology and its processes, while Hong Kong focuses on ICT. Taiwan and China have curricular goals of promoting creativity and innovation. Sweden, Norway and Finland emphasise technique and crafts.

X. D&T education for Indian schools

What kind of technology education, if any, will be appropriate for a population of 200 million in the school-going ages between 5 and 18 years, a very large number of whom have either never enrolled in schools or have dropped out at various stages of education? In India, over half of those who enrol in Class I drop out by Class VIII, and more than two thirds drop out by Class X. Only 20% of those who enrol at Class I reach Class XII, and a mere 7% go for higher education (NFG-W&E, 2007; NKC, 2007). Those who drop out of the education system join – or aspire for – the world of work, most without acquiring employable skills. The nation is still far from adequately training for existing technology roles at the workplace. These are just some of the several compelling reasons to redefine the nature and place of technology in general education.

Challenges of equity and diversity

Catering to about 200 million school going children nation-wide, and hoping to enrol yet another 35 million who are out of school, the country's education system is torn by several conflicting interests (The PROBE Team, 1999). The national attempt to "produce a uniform level of achievement throughout the country" by providing "the same content delivered in the same way" ignores the cultural and regional diversity among Indian students and teachers. The need to promote a plurality of strategies to address the diversity of socio-cultural environments has never been more urgent or important. There are problems of mismatch between culture, educational content and pedagogy (Chunawala et al, 1996; Natarajan et al, 1996). But there is hope for change. Recent National Curriculum Framework documents, and the syllabi and textbooks based on them have attempted to address local contexts.

National Curriculum Framework (NCERT, 2000) document explicitly recognizes science and technology as organically linked and linked to society. Technology is essentially a human activity based on "our" constant desire to improve "our" condition. It is an organized way of creating "purposeful" change. What is not so clear from the documents is whose desires, conditions and purposes are served by either technology or technology education. What is worth teaching is as important as how that is to be taught. There is the challenge, of course, of ensuring contextualisation for diverse socio-economic and bio-geographical settings, while maintaining uniform standards that address content and process as well as cognitive development through at least as many educational boards as there are States in the nation.

Most rural areas have continuing traditions of indigenous and local technological practices despite facing severe odds. There exist wide cultural and resource differences among regions of the country including the rural-urban divide. Education has been perceived to contribute to the alienation of students from rural contexts of work and livelihood. Over 30% of the country's population is expected to be urban in another decade. Most urban classrooms, especially in English medium schools, are multi-lingual, with students coming from as many as a dozen linguistic backgrounds. Making education, especially technology education, inclusive assumes significance in the complex sociocultural context of India, where there is immense innovation potential across the country among the schooled and the unschooled, the formal and non-formal sectors.

Education for a creative work force

The large number of students leaving the educational system by Class VIII implies that a productive and creative work force is possible only by addressing the educational preparation for innovation and creativity at as young an age as possible, preferably from the primary years. Whatever the form, it would be equitable to introduce such a component for all students across the country.

What does school education provide in terms of employable skills such as knowledge and process, procedure, and team work skills? In school contexts across the country, where the emphasis is on studying theoretical principles and observing experiments conducted primarily by the teacher, students do not view science as a collaborative activity (Chunawala & Ladage, 1998). Even work experience, or any of its school-based variations, involves making socially-useful objects using given recipes. It has little scope for design or examining contexts of use.

The education system does not encourage collaboration and constrains modes of expression. This can be alienating to a majority of learners (The PROBE Team, 1999). There is a need, and a rather urgent one, for a distinct model of education for innovation that integrates multiple modes of expression and values teamwork. The model must enable equitable participation of students from diverse backgrounds – rural and urban, of all gender orientations, coming from different socio-economic and linguistic backgrounds, and widely differing levels of exposure to technology and the designed world.

Designing vocational education

The NPE recommends vocationalisation of secondary education. Yet vocational and polytechnic courses at postsecondary level garner a total enrolment of only 1.5% of the total students passing out of secondary school. Of these 50% drop out and a large fraction are “unemployed”. This is a paradox in the face of supply falling short of skilled labour demand. The major problems among several, include a low social status for such courses that largely attract academically backward and/ or economically weaker sections, inappropriate curricula, and absence of effective training for the work place in either knowledge, skills or teamwork.

The National Knowledge Commission (NKC), constituted by the Government of India in 2005 to study various aspects of education, at different levels, has recommended more flexibility in vocational education and training (VET). It also pointed to the need for quantifying and monitoring the impact of vocational education, and suggested re-branding to increase its perceived value and ability to command higher incomes (NKC, 2007). This implies teaching elements of design and critical thinking about technology and society not only to those in the vocational education stream, but also to all students in the generic vocational courses.

Towards a model of D&T education

The questions discussed so far indicate the need for a technology education with equitable access that can generate a creative and productive work force in the face of complex diversities.

The technology education suitable for India will recognize the importance of context for learning and application, and will include design. But several issues of educational significance are still to be addressed. Should technology be clubbed with science? Science and technology share knowledge base and pedagogy. However, the implications of technology education extend beyond knowing science and scientific occupations, to vocational education and even social studies, art, ethics and value education. Clubbing technology with science drains the time available for learning science, which at present is adequate. Besides, the learning objectives of technology are not met. For one, the method of technology as distinct from the method of science is not recognised. It does not address the innovation potential of "doing". Some alternative curricula in countries (other than India) across the world have made serious attempts to redress this by integrating "design" and "make-it-work" activities in their curricular materials in science and other subjects (Ramadas, 1998, 2001).

D&T education research at HBCSE has been guided by an understanding that emerges from a study of philosophy of technology. It is also guided by theoretical perspectives on collaborative learning; cognition and action; concerns of sociocultural and gender appropriateness; and the development of language, quantitative, and problem solving skills. This approach to D&T education emphasises collaborative participation of students in design, making and evaluation of artefacts and systems (Kimbell et al, 1996). It is hoped that design, craft, and technology as part of general education (at the school level) will help attract a greater number and diversity (rural, girls, etc.) of students to careers in technology. The curriculum is designed to equip them with the trainable skills of perceiving and defining needs, and *designing* to satisfy them. The D&T activities will provide a context for students to select, learn and apply suitable techniques and skills and make judgments based on social, ethical and aesthetic values. A preliminary proposal of a curricular framework for a collaborative and communication-centred D&T education is given in Table 2.

At the pre-primary and primary levels (up to Class V), D&T education will aim to engage the child in exploring the world – natural environment, artefacts and people – and harmonizing with it. Exploring locally available materials through multiple senses and modes of expression besides being fun and engaging, will prepare primary students for the formal school subjects of science and social studies they will learn later. It will introduce them to skills of simple tool use and expose them to contexts that need those skills. The D&T tasks will involve the child in hands-on activities to acquire the basic cognitive and sensory-motor skills as well as in making explicit the tacit knowledge of technology.

Middle school students learn to contextualise and negotiate the design problem in groups, investigate potential ideas, plan for making the object, actualise their plan and evaluate the product. Working in groups, they discuss and communicate with other groups. They generate criteria to justify designs, make judgements about materials, joints, tools and techniques, and evaluate products. Thus they develop complex analytical and linguistic abilities. The simple technological units planned at this stage are aimed to give a broader view of technology, which manifests as objects, knowledge and activity. The activities integrate knowledge and skills across school subjects. Students at this level can engage in limited critical thinking exercises and are cognitively ready to appreciate simple links between science, technology and society, which can be introduced in the setting of goals, as well as during all communication sessions.

Students at the secondary and higher secondary levels (Class IX to XII) address simple real world problems for which they design solutions. The units are aimed to sensitise students to local environmental, health and other developmental concerns as they critically think through the connections between science, technology and society. The units involve working with more advanced tools and resources to design complex solutions. At this stage they interact with the local community and establishing the school-community linkages. Critical thinking in the area of science, technology and society is the thrust of the D&T education programme at the higher secondary stage.

Table 2: The study objectives and learning goals of D&T education at different stages of Indian school education.

School Levels	Study objective, learning goals of D&T education		
	Artefact/ system	**Activity/ Skills**	**Language**
Stage 1: Pre-primary, Primary (to Class V)	Materials and their properties	Materials manipulation, skills of simple tool use, estimation, measurement	“reading” and making drawings, articulate tacit knowledge
Stage 2: Middle school (Class VI to VIII)	Simple objects, models and systems	Investigating, designing, planning, making – techniques, skills, evaluating using criteria - material, technical, social, aesthetic, etc.	Evolving and using codes: Exploratory sketches, technical drawings, plans, communication of complex ideas
Stage 3: Secondary school (Class IX and X)	Objects, models and systems for real world needs	Investigating, designing, planning and making, evaluating – STS aspects	Using design codes, Critiquing designs, technical drawings, STS links, community interactions
Stage 4: Higher secondary (Class XI and XII)	Options: objects, machines or systems	Options: survey and analysis projects	Critiquing designs, Critical thinking, STS, community interactions

Assessment

Before any school subject can achieve its educational aims, two major challenges have to be successfully met. First, assessment systems need to be in place that are in conformity with both the philosophical background of the discipline (of which subject is a part) as well as with the educational aims of the subject in developing students' capabilities. School education in the sciences has been struggling to meet these challenges for decades. Technology education shares at least some of the difficulties. The assessment of written examination scripts by hundreds of thousands of students is itself a daunting task. Since 2004, there has been a move by the Central Board of Secondary Education (CBSE) to assess experimental skills of individual students in Class IX and X through their performance in a written test specially designed for the purpose. The experimental activity is beyond the existing assessment systems. As for including creative drawings, models and the process of design and making, an entirely new way of thinking is needed. Perhaps, a more designerly way of thinking than what academicians and educationists are accustomed to!

Teacher professional background

The second challenge is the choice of suitably trained teachers with adequate and appropriate professional preparation. While this problem has been felt in several school subjects, including languages, for D&T education it is more complex. What designers know about their own problem-solving processes remains largely tacit knowledge. Hence design education relies on an apprenticeship system of learning. However, teachers of design need to be as articulate as they can about what it is they are trying to teach, or else they can have no basis for choosing the content and methods of their teaching. The difficulties arising from inadequate subject and pedagogic preparation, subject expertise and inappropriate attitudes among teachers are practical blocks to the implementation of D&T education for all.

While answering questions raised by teachers at the Wardha Education Conference in 1939, in relation to the introduction of handicraft based education for all, Gandhi elaborated that the teacher had to be both knowledgeable in the subjects as well as an expert in the conceptual and procedural knowledge and skills of the craft. This is a tall order.

XI With hope and a prayer

I have shown how multicultural classrooms benefit from communication and collaboration centred D&T activities. D&T has been argued as a vehicle for creativity and design advantage in Indian classrooms. The challenges of curricular issues of D&T education in Indian schools have been briefly addressed. Main among these were suitable teacher background and preparation, development of attitudes for technology education, and assessment methods. It is essential to reconcile meaningful assessment of design and making with the development of an appropriate attitude towards technology in conformation with the philosophical elaboration of technology and technology education. Salient features of a possible D&T curriculum for Indian schools were proposed.

Several issues normally arise when a subject is being introduced or redefined in school education. Most often, technology education at school level seems to involve a movement away from the earlier avatars of crafts, industrial arts, engineering, technical drawing, applied science, etc., towards a greater emphasis on design/ creativity, the content, methods and processes of technology. The different stakeholders, including teachers, teacher educators, policy makers and school systems besides the pupils themselves, then have to grapple with the changes. There are evidences of contextual and cultural flavours of technology education. Vries (2006) writes: “The various themes in the development of technology education are so closely intertwined that describing national developments in terms of separated themes would seriously hurt the validity of that description.” (pp 10) This accentuates the contextual character of implementing technology education.

The educational community has a tendency to avoid radical changes, even if its present state is unsatisfactory. Creativity and critical thinking inherent to D&T education are difficult to manage in classrooms, difficult to assess, and can even threaten existing socio-political systems. Parents and social systems are often uncomfortable with major changes in any aspect of education. Technology education poses an additional challenge by its sheer breadth of concerns. Technology as a notion is fluid and somewhat ambiguous. It is influenced by time and context – geographical, cultural, and socio-historical. This introduces myriad teaching possibilities that imbue the subject with potential for inclusivity and equity, creativity and critical thinking, ecology of thought and action. For its proponents, this is what makes design and technology empowering in the school context.

The current state of the nascent discipline of technology education is characterised by a lot of ferment. Technology education in one form or another exists in several nations in almost all the continents. Africa, Asia and South America, which are large land masses and home to over half the global human populations do not yet figure in global discussions on technology in general education. This may reflect a lack of effervescence/ ferment in technology education as a school subject in these countries. At the same time, the nature of technology education in populous countries like India, as well as China, Indonesia and Brazil can have a significant impact on the global socio-political and industrial scene.

Are we to presume that these nations have failed to perceive any merit in having technology in general education, or at least in the forms that it has assumed in the industrial countries? Is the technology education being perceived as exclusive or differentiated? Whatever the case, it is a matter of concern that India is not yet participant to the dialogues that are shaping the nature of technology education in several nations of the world.

An education which includes experiences of designing and making, which inevitably involves taking qualitative decisions about competing alternatives, will help all people – current pupils and future citizens – return a personally valid answer to the question, "How do I want to live?" These aims urgently call for inclusion of design and technology in Indian school curricula, and hopes that all its empowering possibilities will one day be realised. For India, the urgent need to introduce design and technology in the curriculum harks me to the following words of Tagore (1913) in the English translation of his most famous work, *Geetanjali*:

Where tireless striving stretches its arms towards perfection;
Where the clear stream of reason
        has not lost its way into the dreary desert sand of dead habit;
Where the mind is led forward by thee into ever-widening thought and action -
Into that heaven of freedom, my Father, let my country awake.

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