Designing technology education beyond know-how or know-why

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Abstract
Knowledge in the context of technological systems may be thought of as an understanding of the systems. It represents an understanding of the principles that underlie their functioning (know-why), processes used to create them (know-how), and the uses that these systems serve (know-what). Technology education needs to address students' need to appreciate these types of knowledge and the inter-relationships among them. However, they are acquired through different learning processes that need to be addressed in structuring technology education. First the different types of technological knowledge will be discussed. The following section will argue for an integration of these types of knowledge in school technology eduction. There will be discussions on how the inclusion of design, collaboration and communication in technology education serves the goal. The educational imperatives for including design as well as collaboration and communication will be illustrated with examples from literature and through observations from research conducted over a decade at the Homi Bhabha Centre for Science Education, TIFR.

Keywords: Technology education, know-how, know-why, know-what, design, collaboration, communication

1. Introduction
In technology, *Homo sapiens*, the "understander" meets *Homo faber* the "maker" and forms the powerful liaison between mind and hand. Technological prowess also requires ability to imagine the impossible - and to project what may be achieved in the future based on what can be done now. Technology is a social endeavour, being inspired by human 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 engaged in technology. Since the agricultural revolution over 10,000 years ago, humans have evolved culturally, and along with their cultures, have evolved their technologies (DeGregori, 1989).

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.

A technological activity is task-centred and goal-directed and hence purposeful and focused. It involves making decisions, that must include 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. Technological competence develops through 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). 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.

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 (de 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 discussed 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. Others, like Israel, include projects in science and technology (S&T), while some like Australia emphasize S&T for environmental sustainability. The USA curriculum that is increasingly influences global discussions 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 along with the physical principles underlying the working of technological systems.

Whatever the goals that drive it, technology education must move beyond the divisions between theory and practice, and integrate these categories that have been historically separated in education. Such integration of the knowledge of technology as part of general education for all students serves to enhance society's level of technological literacy and allows learners to contribute to and critique technological developments from an informed position. We are all familiar with the electrical engineer, who cannot a fit a light bulb, and the expert mechanic, who has no clue of the principles of engine design. School technology education needs to be relevant to everyday life and beyond.

Knowledge in the context of technological systems may be thought of as an understanding of the systems. It represents an understanding of the principles that underlie their functioning (know-why), processes used to create them (know-how), and the uses that these systems serve (know-what). The distinctions between these three knowledge components are similar to, but not the same as, that between declarative (may be know-what or know-why), procedural (know-how) and episodic (know-what) memory.

Technology education needs to address students' need to appreciate these types of knowledge and the inter-relationships among them. However, they are acquired through different learning processes that need to be addressed in structuring technology education. Hence, it is essential to first know what constitutes the knowledge for technological capability, the properties of such knowledge, as well as the inter-relationships among the different kinds of knowledge. This will also give a clue to the nature of pedagogical practices that will help in acquiring the knowledge. First the different types of technological knowledge will be discussed. The following section will argue for an integration of these types of knowledge. There will be discussions on how the inclusion of design, collaboration and communication in technology education serves the goal. The educational imperatives for including design as well as collaboration and communication will be illustrated with examples from literature and through observations from research conducted over a decade at the Homi Bhabha Centre for Science Education, TIFR.

2. Know-how, procedural knowledge and skills

Know-how refers to skills or the capability to do something. It represents an understanding of the procedures required to make each component and of how the components should be put together to perform as a technological system. Know-how is created through *learning by doing* (Arrow, 1962; Dutton & Thomas, 1985; Argote & Epple, 1990 all cited in Garud, 1997). Knowledge about how to perform a task accumulates with experience over time, as captured in the adage "practice makes perfect". Besides, prior experience dictates future possibilities. Hence learning by doing is cumulative as well as path dependent.

Know-how may not always get articulated; it may remain tacit. Possibly because of this, know-how is less accessible and has restricted transfer possibility than other forms of knowledge. However, it decays more slowly than the knowledge gained in declarative learning (Cohen, 1994 cited in Garud, 1997). Tacit knowledge can be transformed into explicit or specifiable knowledge through codification, articulation, or specification. Some tacit aspects of knowledge cannot be codified, but can only be transmitted via training or gained through personal experience.

The aims of technology education include enabling students to gain know-how and providing opportunities for articulation. Know-how at the individual level may often be transferred through apprenticeship, or *learning-through-association*. Individual know-how when used coherently in teams can be synergistically more powerful. The power of synergy, however, comes from practice in groups. In order for students to learn through collaboration, they must first learn to collaborate. In the context of school education, students gain know-how in the process of designing and making, working in groups, allows communication and articulation. These aspects are discussed in a later section.

3. Know-why, principles and theories

Industries work hard to protect their know-how, but declarative knowledge or know-why, is often documented in books, as laboratory notes, or journal articles. Know-why represents an understanding of the principles underlying phenomena involved in technological activity. This knowledge is created through *learning-by-studying.* It involves controlled experimentation and simulation to understand the principles and theories that describe how a technological system works. As in the case of know-how, prior knowledge guides the problems addressed, the instrumentation used for addressing them and consequently the solutions arrived at (Garud & Rappa, 1995 cited in Garud, 1997). Hence, like know-how, know-why is cumulative and path dependent.

In technology, it is necessary to associate ideas from unrelated domains and fields to create new ideas (Garud, Nayyar & Shapira, 1997 cited in Garud, 1997). Know-why is highly valued because it can lead to increasing returns on time, money and effort invested in two situations: when knowledge is synthesized through the coalition of different technological and scientific fields (Usher, 1954, cited in Garud, 1997); and when understanding of one system opens up avenues to explore others (Adler, 1989b cited in Garud, 1997). Know-why is multiplicative knowledge.

4. Know-what: needs, suitability and judgements

Know-what refers to knowledge about "facts": How many people live in Johannesburg? What are the ingredients in pancakes? When was the first World War? Know-what also represents an appreciation of which objects, systems, skills, ideas and phenomena are relevant to, and worth pursuing in, the technological activity. For instance, it includes an understanding of who the users are, the specifications/ configurations of the system that they may want, and the different uses that they may put the system to. Users invariably use technological systems in ways different from what they were designed or produced for. These are referred to by de Vries (2006) as accidental and intended or "proper" functions respectively. Designers and makers need to make decisions based on this awareness. An important way to generate know-what knowledge is through *learning-by-using*. Such learning is crucial in the context of technological systems, especially in terms of making contextually appropriate judgements.

Learning of know-what occurs through interactions between users, designers and makers about desirable configuration, technically feasible configurations and the range of possible uses. Because this knowledge is generated through interactions, it does not reside merely at the nodes – that is designer, maker or user – but is created and situated in the relationship among them (Brown and Duguid, 1991). For instance, user preferences evolve as they use products, and the capabilities of designers and makers develop to meet new preferences, giving rise to a dynamic process of product development.

In a rapidly changing environment, as in mobile phones and computers, the acquisition of know-what – of user preferences – needs to be a continual activity. It may not be cumulative. Know-what under such dynamic situations is preserved by modularising the technological system in terms of the functions of its components. This allows designers and makers to substitute some components while retaining others. The possibilities of variations increase with increasing modularity of systems: e.g. physical features of a mobile, its operating system, whether touch screen or *qwerty* keyboard can all be independently varied to suit user preferences. As such knowledge is embedded in the user-designer-maker relationship, know-what itself is not transferable. What needs to be learned is the participation in the interactions that will generate the know-what.

5. Integrating knowledge types through design

Know-why can be obtained through reading books, attending lectures and accessing databases. The other two kinds of knowledge are rooted primarily in practical experience. Know-how will typically be learned in apprenticeship situations. Technological development is driven by both know-why and know-what knowledges. The know-why push comes from S&T developments, while the know-what pull comes from changing user needs.

If there were an hierarchy of the three knowledges, know-how would come before know-why, as it is possible to produce a technological system with know-how alone, but not with know-why alone. Ships sailed the seas long before Archimedes' eureka moment and the theories for floating. And Newcomen steam engines were invented before the study of heat. Besides, know-how can form the base for creating know-why through a learning process that involves systematic experimenting. In other words, experience gained through learning-by-doing can direct research and development for technologically feasible alternatives.

In the process of technological change, while incremental change proceeds on the basis of standard know-how, a radical change is driven by know-why and know-what. Our knowledge of how to bake a cake does not assume that we also know how its ingredients interact to produce a specific cake. But this ignorance prevents us from innovating different kinds of cakes. Without the know-why the designer-makers cannot cater to the changing needs of users. Without know-why, an adequate understanding of underlying principles, it is not possible to predict how changes in one component may affect the performance of the system. Know-why is essential for making informed improvements and changes. Know-how then adapts, incorporating the newly created knowledge. Given the modern dynamically changing user preferences, technologists need to have the capability to synchronise the creation and use of appropriate know-why and know-how to serve the continually changing know-what.

Technology and design are organically linked. Designing a technological system involves the ability to decompose a system into its parts. This entails the knowledge of each component as well as how they are integrated. It needs an understanding of how a set of components are put together (know-how) and why the components interact with one another to provide the product's function (know-why), as well as the specific configuration that users want (know-what). A general education in technology should aim to help students gain and connect the three types of knowledge. One way to achieve this would be through engaging teams of students in activities and decision making that involves all three knowledge types.

Design exploration, the initiation of the technological activity, serves as a platform for integrating the three knowledges – know-how, know-why and know-what. Technology education must reflect diverse practices in the community and offer students opportunities to develop understandings not only across knowledge types, but also cultural perspectives. It must include an understanding of the inter-relationships between technology and society: it must be immersed in the cultural context of the learners, while giving a perspective of the diversity of technologies around the world. The most compelling arguments for including Design and Technology (D&T) as part of school education arise from what it means to be human. Students, as they design, struggle simultaneously with the specifications or product goals (know-what, or what the user wants), their understanding of the procedures to achieve it (know-how), and using their knowledge of how it works (know-why) to choose among competing alternatives.

6. Design and technology in school education: counting the benefits

An insignificant fraction of those who pass out from school opt to study engineering, design or technology at the tertiary level. In school, science is considered an important subject, while vocationalisation has failed to find favour among students and parents in countries like India. Creativity is often associated with the arts, and innovation has been completely sidelined, or left to an elite in higher education. School students are given scant opportunities for design or technological innovation. At best, schools do not teach technology; they teach 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. An education in technology would serve to address Mahatma Gandhi's concern for students learning through engagement in socially useful and productive work.

"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)

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)

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, can take better control of their own environment.

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).

Design and cognition: A central feature of design activity is the quick generation of a satisfactory solution, rather than any prolonged analysis of the problem. All the necessary information is never available to the designer: design problems are characteristically ill-defined or ill-structured. The solution of such problems calls for and sustains 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 (Lave and Wenger, 1991) and followers of Bruner 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. There is a need for the development of such modes of cognition through general 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).

Design processes lead to learning at high cognitive levels by supporting students in working with many different representations and learning modalities – verbal, analytical, visual, concrete. (van Someren et al., 1998) Modelling, is more than a technique; it is a way of thinking that permits the integrated exploration of complex conceptual spaces. (Sabelli, 2006) Modelling with its accompanying simulations and visualizations, can be part and parcel of the process of diagnosing and repairing physical systems, as much as it is part of the process of designing them.

Design communication: 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.

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 non-verbal modes, graphic images like drawings, diagrams and sketches as well as the use of mental imagery.

Technology as social endeavour – role of collaboration: 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. 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.”

Collaboration, according to Roschelle and Teasley (1995, p.70), refers to a ‘coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem.’ Cooperative learning, on the other hand, 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).

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, analysed 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.

7. 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 and Africa 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; an important one concerns the pedagogy for integrating the knowledge types for building technological capabilities. Science pedagogy does not address the innovation potential of "doing". Alternative curricula in some countries (other than India) have integrated "design" and "make-it-work" activities as part of curricula. (Ramadas, 1998, 2001).

Design and technology (D&T) education research at the Centre 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. A series of research studies at the Centre over the last decade have addressed several aspects of a curricular framework for a collaborative and communication-centred D&T education. These studies carried out in different Indian school settings will be used to illustrate how learning to design and make at the school level can help integrate the know-how, know-why and know-what in technology.

Figure 1: A model of D&T education centred on collaboration and communication. (Choksi et al, 2006)

(a) A pedagogy for D&T education among middle school students: The "collaboration and communication centred D&T education" model (Choksi et al, 2006) developed at the Centre is inspired by the UK curricular model - the Design-Make-Appraise of APU (Kimbell et al, 1996). Three D&T education units were developed through classroom trials among 11 to 13 year old students from three different school settings. The units were on bag-making, wind mill model making, and puppet making and putting up a puppet show. Middle school students contextualised and negotiated the design problem in groups, investigated potential ideas, planned for making the product, actualised their plan and evaluated the results. They generated criteria to justify designs, made judgements about materials, joints, tools and techniques. They developed complex analytical and linguistic abilities. (Khunyakari et al, 2007; Mehrotra et al 2009; Khunyakari et al, 2007a)

Students talked and wrote about related artefacts, and discussed their structures and functions. Students explored their own ideas through group discussions and design sketches, used quantitative reasoning skills to depict their design, and anticipated the making sequences, including work distribution among members of their group. Communication and collaboration occurred at various levels intra-group and intergroup. They discussed within groups, informally communicated with other groups and made formal presentations. Students' engagements through talk, gestures, sketches and models gave evidences that they were integrating know-why and know-how. There was collaborative completion of design production and shared understanding of the design ideas among group members: once explored and conceptualized, the design remained in the shared memory of fellow designers and makers. Skills and tool use procedures were practised in authentic problem solving settings.

Know-how developed through design and making, and become explicit through collaboration and communication in multiple modes. The structured communication of design, planning and evaluation also helped students articulate the know-why that they had associated with the tasks. The know-what was elaborated through initial contextualisation and know-why and know-what through continuous justification of materials and methods.

(b) *Route maps based on verbal directions:* In another study that aimed to study the spontaneous generation of icons and symbols in design settings, students made a route map based on given verbal directions. In this study, 96 students generated 30 different icons to depict the 10 landmarks given in the verbal description (Ara, 2007). They also used 8 different graphical symbols for depicting streets. Know-how is developmental and contextual.

(c) *Depiction of objects and assemblies based on verbal cues:* The contextual nature of know-how development was seen in another study among middle school students, who made representations of simple, complex and dynamic objects and object assemblies based on verbal description or cues relating to these objects. They had to depict and describe artefacts that included simple pipes and solid cylinders, their assemblies, 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 depict proportion of the objects to the dimensions given in the text. Besides, handling objects of similar shape and 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.

(d) *Appreciation of artefact design – form and function:* Two studies aimed at sensitizing students to issues of design and to make them appreciate that form and function are closely linked. On the other hand function affects form: e.g. only round things roll. One addressed the strategies used by middle-school students, working in dyads, to identify the intended functions of 3 artefacts unfamiliar to them: different kinds of knife sharpeners. (Ara, Natarajan & Chunawala, 2009) The results suggested that intra-group interaction played an important role in identification of the intended function of the artefacts. Another study analysed students' evaluation of the different types of tongs presented to them in terms of (a) students' self-generated criteria to evaluate and compare the pairs of tongs, (b) students' testing strategies while evaluating the tongs and (c) their redesigning strategies. (Ara, Natarajan & Chunawala, 2011) It was found that students tested the products for their efficiency and generated criteria predominantly related to their functions and ergonomics. They categorised the tongs largely based on perceived similar actions of the tongs and their appearances. These studies addressed pedagogic strategies that enhance the know-what knowledge of students in the context of design of artefacts.

(e) *Designing solution to a real problem without making:* In this study, students were given the brief to "design a device for Rita's grandmother so that she can easily lift the sewing or knitting needle from the floor without bending." (Ara, Natarajan and Chunawala, 2010) Students working in groups had to produce 2 design solutions. All the designs showed elements of creativity, imaginative thinking, used one or more scientific concepts, such as magnetism, air pressure, air suspension and an understanding of the use of some technological concepts, such as the use of remote control car, telescopic rod, pulley and gears. The groups consistently kept the user in mind when designing the artefact. All the groups also decided on the cost of their designed artefact. Some even enhanced the quality of their design by increasing the possible uses of their artefacts. This study provided a rich context for students to integrate know-why with know-what. Though students implicitly used their understanding of the know-how, they were not required to demonstrate or practice it.

(f) *Designing and making a model of a playground on a plot of given land:* Student groups of 3 members each explored the designs of items they would have on the playground, planned the scale model they would make, chose materials for the model, communicated their design and plan to the class for suggestions, made their chosen item and evaluated all items. They estimated, measured and mapped, used tool, and showcased social and interpersonal skills, used concepts of stability and strength in relation to balance and shape. Students identified problems and developed strategies to fix them. They empathised with differently abled persons, showed concern for safety and attention to aesthetics. They critiqued their own and others' work. Students worked in a context of project based learning and gained all three types of knowledge. (Shome et al., 2011)

The studies at the Centre showed that 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 – the know-why and know-how. 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.

8. Conclusion

An important justification for D&T in general education comes from its integration of episteme (knowledge), techné (skill), and phronesis (practical wisdom) (Dunne, 1993). 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)

Technical or vocational education normally 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.

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 large number of students leaving the educational system well before college 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.

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 including the rural-urban divide. Education has been perceived to contribute to the alienation of students from rural contexts of work and livelihood. Making education, especially technology education, inclusive assumes significance in the complex sociocultural contexts of India and Africa, where there is immense innovation potential among young people in the schooled and the unschooled, the formal and non-formal sectors.

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 idea is fluid and somewhat ambiguous. It is influenced by geographical, cultural, and socio-historical contexts. This introduces teaching possibilities for inclusivity and equity, creativity and critical thinking, ecology of thought and action. For some of us, 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 and several African Nations are not yet participants to the dialogues that are shaping the nature of technology education around the world.

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