INVESTIGATING MIDDLE SCHOOL STUDENTS' PERCEPTIONS OF TECHNOLOGY AND DEVELOPING DESIGN AND TECHNOLOGY EDUCATION UNITS TO STUDY STUDENTS' DESIGN PRODUCTIONS

Synopsis

Submitted to the
Tata Institute of Fundamental Research, Mumbai
for the degree of Doctor of Philosophy
in Science Education

by

Ritesh P. Khunyakari

Thesis advisor: Prof. Chitra Natarajan

Homi Bhabha Centre for Science Education
Tata Institute of Fundamental Research
Mumbai

January, 2008

1 Introduction

The work described in the thesis is a step towards generating research inputs for developing Design and Technology (D&T) educational units for Indian classrooms. The research and development initiative in D&T education at the Homi Bhabha Centre for Science Education (HBCSE) began with a survey of ideas about technology among Class 8 (age 13 years) students. A questionnaire developed for the purpose was administered to students in urban and rural settings and those coming from English and Marathi medium schools in and around Mumbai. Building on insights from the survey and an understanding of issues in philosophy of technology and technology education, three D&T education units were developed through trials that engaged students in designing and making artefacts or systems. Trials of the three units were conducted in three socio-cultural settings. The thesis reports on the survey, the development and trials of the D&T units and aspects of cognition in students' design productions.

2 Background and rationale

Technology has been an inseparable part of the realm of human activities and our inhabited environment. In fact, modification of our environment by design rather than instinct distinguishes humans from other living kinds. Human engagements with technology involve "making" or manual work, which serve another purpose. From the tool-maker to contemporary humans, and from the child engaging in sensory-motor activities to the gesturing adult, that is, whether from a historical or developmental viewpoint, kinaesthetic engagements can be seen as tools of cognition. Educational philosophers, Vygotsky and Dewey have emphasized the need for integrating practical aspects of learning and doing in formal education. These ideas are reflected in the educational models of Gandhi and Sister Nivedita as well. Unfortunately concepts and praxis are seen in isolation in systems of formal learning, which tend to compartmentalise these aspects. This imposed duality has fissured our perception of human activity into the mental and the manual, which runs deep in our culture. Technology can influence both concepts and practices to bridge this gap (McCormick 1997). Any technological activity draws from a range of specific knowledge, skills and values to meet the demands of contextual situations. Technology transcends the predominantly disciplinary approaches to problem solving.

In spite of all these, technology as a discipline of school learning has yet to establish itself in all the countries of the world. An apparent confusion in the meaning of the term *technology* may contribute to the absence of technology as a subject in schools. Some limit the meaning of *technology* to applied science. For them, teaching science adequately prepares students for doing technology. Others see technology as a vocational subject. There are yet others who relate technology with the crafts. Art and craft in school would then prepare students for engaging with technology. In India, technology is not a school subject. It is explicitly seen as applied science. Premier institutions like the Indian Institutes of Technology (7) and National Institutes of Technology (20) offer formal courses towards preparing engineers and technologists. The Industrial Training Institutes offer training in industrial and trade skills for students in the age group 15+ years. In all these interpretations, some elements of technology activity are obscured. The possible approaches for teaching technology and the means they convey often result in a narrow and limited perception of technology.

The term *technology*, with related words like technique and technical, is ambiguous in English, while languages like Latin and German have a plethora of words to describe ideas relating to technology. The diverse meanings that people associate with the term is evident in its definitions. According to the Cowles Encyclopedia of Science, Industry and Technology: "the human development of any aid – physical or intellectual – in generating structures, products, or services that can increase [hu]man's productivity through better understanding, adaptation to, and control of, his[/her] environment" (Berkner and Kranzberg 1969). This definition that focuses on efficiency and control, contrasts with the definition used in educational contexts. The Standards for Technological Literacy document includes the role of humans in its definition of technology as "the diverse collection of processes and knowledge that people use to extend human abilities and to satisfy human needs and wants" (ITEA 2007). The definition of technology, when seen as that which satisfies "human needs," becomes dependent on humans and their contexts, and as a "diverse collection" includes all such contexts as well.

Though technology has been defined in such broad terms for educational purposes, philosophers have long argued about ways of characterising and defining the nature of technology. One of the useful ways of understanding the nature of technology is in terms of its four manifestations suggested by the philosopher Carl Mitcham (1994): as artefacts, processes, knowledge and volition. Philosophical debates on the nature of technology or issues that pertain to the methodology (process) of technology give valuable insights about perceptions of and practices in technology.

De Vries (2005) outlines the relevance of philosophy of technology for technology education as: (1) a source of inspiration for the content of a curriculum and contexts of teaching and learning, (2) a conceptual basis for an understanding of technology that will help technology educators respond to classroom situations, (3) helping position technology among other subjects, and (4) helping identify the agendas for research in technology education. Design is an essential component of technological activity (de Vries 1992, Barlex 2005) and is often argued as the methodology of technology (Williams 2000). Technology educators need to be aware of the "expert" understanding of technology as well as know the spontaneous perceptions of students so that they can structure suitable educational experiences.

Studies on attitudes towards technology investigated in industrialised and developing countries revealed that students and pupils more readily recognize technology as objects than as other manifestations of technology (knowledge, processes and volition). In general, students relate technology to computers and perceive it primarily as 'high tech' (de Vries 2005). Studies in the Indian context have been few and have surveyed post-school students (Rajput, Pant and Subramaniam 1990). Hence, there was a need to probe perceptions of Indian middle school students from urban and rural settings with differential exposure to technology.

Besides students' spontaneous ideas of technology, design of technology education curriculum needs to get inputs on content and pedagogical issues as well. Technology education lacks a theoretical grounding of research in learning and instruction (de Miranda 2004). Research in this area suffers from a lack of coherent focus and direction, especially with regard to cognition and learning (Zuga 2004). Zuga diagnoses the lower number of active researchers, complacent attitude in working with little data, collective opinions and prescriptive content, absence of a theoretical perspective guiding research and lack of clear content, as reasons for the problem. She suggests that observations of student engagements can give valuable insights of ideas and concepts that students use and learn, and how they learn. Encouraging action research would help widen the research base. She also suggests the need to ground research in a theoretical perspective and to identify constructs and concepts that are to be learnt through a technological activity. These concerns were addressed in our research study.

De Miranda (2004) advocates grounding the teaching of technology in the well-researched tradition of cognitive sciences. According to him, cognitive models of learning and instruction allow for active roles to both teacher as well as the learner and are critical to bridging the gap between theory and practice. In the learning process, the student reflects, monitors, evaluates and engages in self-regulation while the teacher is a facilitator, who helps students and provides opportunities for engagement and expression.

Visualisation of the anticipated artefact is central to the technology activity of "design and make". Besides, design is a fundamental human capacity to plan and model ideas with an intent to address the real-life ill-defined problems (Roberts 1994). Transformational reasoning afforded by sketches and diagrams result in a facilitation of the imaged mental process (Tversky 2005). Interaction between the mind and the hand is the essence of design and technology, and *why* and *how* pupils chose to do things are more important than *what* they chose to do (Assessment of Performance Unit 1994). However, the cognitive aspects of design learning have been neglected in research in both design (Oxman 2001) as well as in technology education.

Our research addressed the broader concerns of the nature of technology, content and pedagogy suitable for diverse contexts, boys and girls, and aspects of design and cognition. These were addressed through the choice of the D&T units, the sample, the structure of trials, classroom organisation, the productions generated, the data collection and analysis.

3 Research objectives

The research study had three broad objectives:

- To study middle school students' (age 13 years) ideas about technology by developing a survey questionnaire for the purpose and administering it to Class 8 students from schools in and around Mumbai.
- To develop D&T education units through classroom trials among students from urban and rural middle schools with English and Marathi medium of learning.
- To analyse the trials of D&T education units for content and pedagogic aspects in classroom observations, and for cognitive aspects in students' design productions.

4 Organisation of the thesis

The thesis begins with a report of a survey aimed at understanding middle school students' ideas about technology. The section on survey methodology deals with the development of a suitable instrument, choice of sample for study, pilot testing and validation of the instrument, data collection for the final survey and the framework used for analysing student responses. Analysis is discussed in the next section.

The thesis next focuses on the development and trials of three D&T units, discusses the sample, method of the development-trial iteration, and data collection. The subsequent sections discuss first the framework for analysing classroom observations and then the salient results obtained, followed by a framework developed for analysing students' design productions and the results so obtained.

A section on conclusion and implications attempts to provide a coherent view of the findings and its implications for education in general and technology education in particular.

5 A survey of middle school students' ideas about technology

Findings of Pupils' Attitudes Towards Technology (PATT) studies and Views on Science-Technology-Society (VOSTS), carried out with students from different cultural backgrounds and at different age levels, pointed to some of the common perceptions of technology among students mostly outside India. An earlier study among students in the age range 10 to 15 years used posters as a means to probe students' *images of technology.* The study revealed that students depicted technology as a collection of objects, especially those related to communication and transport (Mehrotra, Khunyakari, Chunawala and Natarajan 2003). Besides, the idea of *technology* is elusive and has context-dependent meanings. It is influenced by exposure to technology, which rapidly changes with developments in society, as well as an understanding of the history of technology.

A survey questionnaire different from those in earlier studies was developed that included technology in situations, especially relevant to Indian context, required them to rate technological objects and activities and integrated a pictorial part as well.

Developing the questionnaire involved listing themes relating technology and aspects of students' lives: students' interests, the objects, activities, knowledge and skills they associate with technology, and volition, e.g. values, opinions on consequences, etc. that they hold. The "volition" theme follows Mitcham's idea that technology is manifested through knowing the use of technology and recognising its consequences. The themes summarised in Table 1, thus covered all manifestations of technology as discussed by Mitcham (1994).

Diverse question formats were used to avoid monotony in the questionnaire: 3-point rating scales (no/low/high), dual option questions (agree/disagree, yes/no), multiple choice - single response, multiple choice - multiple response. Flexibility of responses was addressed through subjective questions that would evoke spontaneous ideas from students. The questionnaire was first developed in English, the language of choice among the researchers and was then translated into Marathi. The questionnaire had 5 parts: (a)

Themes	What the theme probed
Technology and students' interests	Relation between technology and students' future plans and ambitions
	Links between technology and knowledge, skills and school subjects
Technology and objects (artefacts)	Students' ratings of level of technology in each of the given objects
	Association of technology with locations
Technology and activities	Students' ratings of level of technology in each of the given activities
Technology and knowledge	Judgements about prior technological knowledge helping one perform better in given occupations
	Students' choices of occupations as suitable for a male or a female
Technology and volition	Consequences and qualities attributed to technology, and uses and goals associated with technology at individual and societal levels
	Students' reactions to situations of technology change

Table 1: Themes related to technology that were probed in the survey questionnaire.

introduction, including guidelines for students; (b) request for personal information such as, name, age, school and career choices; (c) free response question (like an idea map) on technology; (d) ratings and other close-ended questions; and (e) pictorial rating type question. Development of the questionnaire and preliminary findings have been reported in an international symposium (Khunyakari, Mehrotra, Natarajan and Chunawala 2003).

5.1 Sample

The survey study was carried out with Class 8 students, age 13 years, and involved a pilot and a final survey. The research objectives guided the sample choice. The sample included representation of (i) students from rural and urban settings, (ii) students from schools with the two most commonly encountered media of formal learning in the State, namely, Marathi (language of the State of Maharashtra) and English, and (iii) girls and boys. The sample distribution for the pilot and final survey is summarised in Table 2.

	Pilot (3 schools)							**Final** (11 schools)						
	Marathi			English			T	Marathi			English			T
	G	B	T	G	B	T	NT	G	B	T	G	B	T	NT
Rural	20	41	61	0	0	0	61	92	66	158	0	0	0	158
Urban	19	36	55	16	35	51	106	119	112	231	116	139	255	486
Total	39	77	116	16	35	51	**167**	211	178	389	116	139	255	**644**

Note: G: Girls; B: Boys; T: Total; NT: Net Total

Table 2: Sample distribution for the pilot and final surveys.

5.2 Pilot survey and validation

The pilot survey involved a total of 167 students from 3 different co-education schools representing six groups (Urban Marathi Girls and Boys, Urban English Girls and Boys, and Rural Marathi Girls and Boys). It included 14 questions with about 350 items. Students took about an hour and a half to complete the questionnaire. The queries by students during the pilot survey and analysis of their responses provided clues for refining the language and overall content of the questionnaire. The shorter refined questionnaire also with 14 questions but with lesser (250) items was content validated. It reduced the data gathering period to an hour.

5.3 Final survey

The final survey was administered to 654 students and 644 valid responses were obtained from 11 schools, of which 3 schools were single sex schools and the rest were co-educational schools. The questionnaire was tested for reliability using the *test-retest* method, where the same sample responded twice to the same questionnaire: a short interval of 14 days between test and retest, and a long interval of a year between the tests. The reliability analysis using the short and long time intervals for the 8 questions with more than 10 items yielded a high correlation coefficient for both the time intervals: 0.91 - 0.99 for short interval (N=38) and 0.79 - 0.97 for the long interval (N=30). Data gathered was numerically coded and analysed using Statistical Package for the Social Sciences (SPSS) following a framework for analysis indicated below.

5.4 Analysis Framework

Analysis of the data was carried out using a variety of statistical tools. Descriptive analysis revealed the general trends in the frequencies of responses for the entire sample. Researchers made conjectures based on students' responses and studied the influence of the 3 independent variables, namely; (a) settings - Urban and Rural, (b) Medium - English and Marathi, and (c) Sex - Girls and Boys.

Data was then subjected to inferential analysis. Statistical tests were conducted to ascertain whether the responses to the items differ significantly for the two groups within each variable. Exploratory factor analysis was carried out on 8 of the total of 14 questions which had measurable items equal to or more than 10.

Exploratory factor analysis was performed using the method of *principal component analysis*, which analyses the total variance and attempts to explain the maximum amount of variance by the minimum number of underlying factors. Some factors explain more variance than do others. The underlying factors are to be interpreted by extracting the meaning from the set of items that get associated with a factor. The Kaiser-Meyer-Olkin (KMO) test, with a value of 0.5 or higher, and a significant score on Bartlett test of sphericity are statistical measures to confirm the suitability of data for factor analysis. Items with similar frequencies were associated with a common factor.

6 Summary of the survey findings

The findings that emerged from the analysis of response trends are discussed according to themes outlined in Table 1. Trends within each of the three independent variables are compared in the following section.

6.1 Technology and students' interests

The question on students' interests and aspirations addressed students' perception of their need to know technology in order to meet their future plans and their preference for *making* versus *buying* a toy. Over 85% responded that they needed to know and use technology to meet their future plans. More than half of the sample preferred to make a toy rather than buy one from the market. This expression of interest was used in the trials of our D&T units to engage students in making paper models of artefacts such as paper boats, camera, pans, etc. The level (high, low) they attribute to familiar technologies are revealed through questions on objects, activities and locations.

Technology and objects (artefacts)

Objects or artefacts are the most common and frequently encountered manifestations of technology (Mitcham 1994, de Vries 2005). But which objects are seen as high technology, or to what extent (*low* or *high*) are objects considered to involve technology was probed requesting responses on a simple 3-point Likert-type scale to a list of 65 objects depicted in pictorial form. Another question probed students' perception of technology in different places. The factor analysis showed that those locations that have objects with a similar rating of technology level are also associated with each other.

A large proportion of student responses (in the range of 55% to 90%) in all settings responded that electronic and electrical objects such as computer and television were *high* technology. A mix of factors seem to play a role in ascribing the level of technology to a particular object. However, some ideas that governed the rating of objects as involving *high* or *low* were very clear.

Manually operated devices such as office tools, implements and mechanical hand-pumps were rated as involving *low technology*. Similarly, musical instruments were rated as involving *low* technology, while sport-related objects as involving *low* or no technology. On the other hand, students rated objects running on petroleum derived fuels, including transport, and electric appliances as involving *high* technology. It appears that kind of power used to operate or *run* objects, was a factor that influenced the rating of an object by students.

A temporal factor also seemed to guide their ratings of an object: older the origin of object, lower its technology. Modern mechanical devices (around the post-industrial era) and those involving complex operations were rated as *high* technology in contrast to the ancient mechanical objects (e.g. sword, bullock cart) which were rated as *no technology.* This may partly be influenced by the kind of power that drives the object as well. The factor analysis showed large loading on more than one factor.

Microscope, syringe and laboratory apparatus, which are specifically related to science, were seen as *high* technology, while fountain pen and scissors were rated as *low technology.*

Among locales, toilet was widely seen by almost half (49%) of the sample as not using technology. The pattern of responses on locations such as toilet, market, bus depot and fair (mela) were associated through a common factor, possibly, *rural public spaces.* On the other hand, airport, railway station and factory were locales that were associated through a factor. These locales involve transport and communication artefacts, which the majority of students had perceived as *high* technology.

Technology and activities

Students' responses to a range of activities were influenced by the rating of technology in the objects they used. Activities using objects that run on electricity were perceived as involving *high* technology: manually drawing water from a well involved no technology but drawing water using an electric pump involved *high* technology. Sports equipment (objects) and playing games (activity) were perceived as involving *low* technology.

Activities requiring prior training in manual skill were rated as involving *high* technology (e.g. plumbing, making fire crackers). The same activities associated together as a major factor among the three main factors in factor analysis.

Routine household activities like sweeping, making *veni* (flowers tied on a thread used by Indian women for decorating their hair) and polishing shoes were rated as involving *no* technology. Non-domestic and professional activities like welding car, parts, guarding borders of a country, plumbing, wiring electrical connections were seen as involving *high* technology.

Technology and knowledge

Students' perceptions of whether prior technological knowledge was needed to perform better in the given professions gave a clue to the kind of knowledge students associate with technology. There was also a question probing their opinion on the suitability of an occupation for a male, a female or both.

More than 90% of the sample perceived scientist, computer engineer and doctor as professions using technological knowledge. These professions are seen to enjoy *social privilege* and are also known for attractive remunerations. The response trends possibly reflect the social esteem of these occupations and the aspirations of the students and their parents.

Of particular interest are occupations that were not generally seen to be needing prior technological knowledge (response range 37% to 52%), like cook, carpenter, dancer and potter. These artisans, as opposed to people in other trades, like mechanic and electrical wiring, are possibly associated with gaining their know-how, skills and techniques through apprenticeship gained outside formal institutions.

Students were encouraged to advise two of their friends, a boy and a girl, on the occupations they should choose. Students' preferences of occupations for a boy or a girl tended to mirror prevailing social stereotypes in Indian society (Chunawala 1987). A large number of occupations were advised for a boy while only 3 occupations, namely; Nurse (74-90%), cook (57-76%) and dancer (39-61%) were seen as suitable exclusively for a girl by students among all the sample. These 3 occupations associated together into a factor in the factor analysis of the question on the need of prior knowledge discussed earlier as well as the question discussed here on occupations advised.

Technology and volition

Volition relates technology to the context of its use in personal ways: aesthetic, economic, socio-cultural and ethical values, consequences of use for individuals and society, and decision making based on the knowledge.

Most students (range 46% to 84%) chose several positive effects of technology on society: it gets work done faster, helps countries progress, increases comfort, helps wealth creation, removes poverty, is "not likely to make country dependent on others," and "does not make the poor poorer." Besides, all positive qualities given in the question, such as safe, easy, useful, etc. were associated with technology. In the factor analysis too, these items were associated with a factor.

In response to a question probing the extent of need (very much, not much, etc.) of technology to achieve given goals, students felt that technology was required more for the country's progress and for speeding up work than for environmental and food related goals. About half the sample of students, felt that technology brought people together and promoted creativity, but involved high maintenance costs. This response was related to the question discussed earlier on artefacts, where transport and communication were rated as involving *high* technology.

To three situations of technological change involving introduction of new technologies such as high yielding seeds, a new computer in a class or country's decision to go in for a nuclear plant, students' responses were a curious mix of caution and risk-taking. They were willing to try new technologies, but were conservative about accepting products of new technology.

Apart from the general trends, a few differences with respect to urban and rural setting, and girls and boys are reported. The gender aspects are discussed together below.

Urban-rural differences

Students' perceptions were influenced by their experiences of technology. Urban students recounted a greater number and variety of ideas about technology than did the rural students. Urban students rated constructing a house as involving *high* technology, while rural students were divided in their views on this activity. Urban students, most of whom lived in multi-storey buildings, saw professionals like architects, engineers and semi-skilled masons construct them using a variety of modern equipment and structural materials. Rural houses are built largely through manual labour using local materials.

Schools in rural areas have poor facilities and face frequent power failures. The response trends reflect this where students from the rural sample more than urban ones saw technology at home rather than in schools (Rural: home-60%, school-39%; Urban: home-69%, school-62%).

Urban students, who are familiar with offices, where secretaries use computers, typewriters, and other labour saving devices, rated these artefacts as involving *high* technology. Interestingly, they were divided about whether a secretary uses or needs technological knowledge. Thus, the notion of technology associated with artefacts is perceived as very different from technological knowledge needed for an occupation.

Gender aspects

Gender aspects studied were of two types: (1) Activities, occupations that were rated as suitable for boys only, for girls only or for both; and (2) Differences in responses to the questionnaire from the girls and boys in the rural-urban settings, and English-Marathi medium.

A question asked students to assign each task in a given list of 10 tasks to either a girl (Meeta) or a boy (Suresh). The tasks had to be completed in the shortest possible time before they could go out to play. Tasks related to organising objects indoors, such as arranging utensils on a shelf (94%), dusting the house (86%) and watering plants (65%) were assigned to Meeta by a majority of students, while a larger number assigned outdoor or technical tasks like collecting grocery from a store (64%) and replacing a fused bulb (86%) to Suresh.

Girls and boys assigned the occupations of Nurse (B: 86%; G: 83%), Cook (B: 62%; G: 69%) and Dancer (B: 42%; G: 53%) as suitable exclusively for girls. These occupations were also associated with a factor in factor analysis. Carpenter, mechanic, soldier, potter, mill worker, shopkeeper and pilot were perceived as suitable for boys. Doctor, TV news reporter and teacher were the only occupations seen as suitable for both, a boy and a girl, among all students. A similar trend was noted in an earlier study with middle school students in the age range 14 to 18 years, where medicine and teaching were the careers chosen by both sexes (Chunawala 1987). Occupations needing specific tools, hardware, technical skills and know-how were associated with boys.

Most students in the rural sample assigned an equal number of tasks to both Meeta and Suresh while a majority of urban students assigned fewer of 10 tasks to Meeta. Besides, almost half the rural sample (46%) saw the vegetable seller as an occupation appropriate only for a girl.

Boys rated more activities (9) as not involving technology than did girls (5). Over a third (40%) of all the girls rated weaving cloth as involving *high* technology, and an equal proportion of boys (41%) rated it as involving *low* technology.

Objects that did not use an external power to work and activities that did not involve tools and technical skills were perceived as less technological than those that did. There is a need to make an effort in school education to challenge such narrow perceptions of technology by engaging students in a variety of technological activities.

7 Development and trials of D&T education units

The survey analysis threw light on the nature of students' perceptions of technology manifested as objects, in activities, as knowledge and volition. The development of D&T units took into account these perceptions while designing classroom interactions that would help students acquire a broader understanding of technology. Besides (i) students' perceptions, (ii) content of technology, (iii) teaching-learning aspects and classroom interactions, (iv) resource use, (v) cognitive aspects, (vi) evaluation of process and product, and to a lesser extent assessment of students were the six different aspects addressed through the development and trials of the D&T education units. The six aspects draw inspiration from the philosophical position on learning and teaching design and technology education (Kimbell and Stables 2007). This section discusses the sample selected for trials and the methodology followed in the development of the D&T units and trials.

7.1 Sample: the three settings

Between 20 and 25 students in class 6 (age range 11 to 14 years), with near equal numbers of girls and boys from three schools were selected from among those who volunteered to participate in the study. The three schools representing three socio-cultural settings were: Urban Marathi medium, Urban English medium and Rural Marathi medium schools. The relative proximity of the schools to the researchers' workplace, and earlier work by the researcher's institute with these schools also influenced the specific choice of schools.

7.2 Methodology for development of D&T units

Prior understanding that students and teachers bring to the classroom shapes learning. Survey studies formed a means of gathering prior conceptions about technology as a precursor to the development of D&T units. For example, students across all sample types saw electric, electronic goods and fuel-run devices as high technology. Significant differences were noted among the sample types indicating effects of differential exposure and access to technologies. Engaging students in activities involving a range of artefacts may help them see the aspects of technologies in several everyday artefacts, processes and systems.

Several criteria were used for the design of the three units. The nature of the artefact to be designed could be a static product of individual use or a model of a machine system meant for social use, or it may be a system of artefacts. The artefact may range from being simple and static to complex and dynamic assembies. The extent of collaboration required and the knowledge, procedures and skills involved in designing and making the artefact may vary. The level of familiarity of both the context and artefact may differ. The criteria for choice of units have been reported in a publication (Khunyakari, Mehrotra, Natarajan and Chunawala 2006).

Besides considerations of familiarity, complexity and manifestation (object, process, knowledge) of the artefact, the unit selection was influenced by our judgements of local technological practices, students' exposure to material resources, their skills in handling materials, as well as their preparedness for concepts that could be taught through a unit. The three D&T units developed involved designing and making the following:

1. A bag to carry a few (at least 5) books.
2. A working model of a windmill that can lift given weights.
3. A puppet character by each group, and collectively staging a puppet-show.

Concepts, procedures and skills expected to be acquired through each unit were planned based on the knowledge and skills gained by them in earlier years as revealed by the school syllabus, and our interactions with the schools. The structure of our D&T units was inspired by the Assessment of Performance Unit (APU) model that advocates the Design-Make-Appraise (DMA) approach for teaching technology to school students from the primary through secondary levels practised in UK (Kimbell, Stables and Green 1996). The model has been modified to suit the research aims as well to study collaboration and cognition in classroom interactions through gender and other socio-cultural lenses, like the school setting. The development and trials recognises the value of engaging students in collaborative problem-solving (Hennessy and Murphy 1999), which also is integral to the notion of the technology stance (Rowell 2004). The technology stance integrates social aspects of technological activities in school learning. According to this view, discourses around design and designed systems, mediated by use of tools, resources and language, address decisions made by people in using materials and building devices which impact the way humans live. Tradeoffs due to constraints, anticipation of possible failure, assessment of risk and human judgements, are integral to technology practices within an active community like a classroom.

The development was guided by the idea of technology not as a prescribed set of activities but as an engagement in design problem solving through a loosely structured sequence of activities. The *communication and collaboration centred model* for teaching technology to middle school students had the following sequence of activities (Choksi, Chunawala and Natarajan 2006):

Motivation and investigation: Informal discussions among researchers and students initiated the interaction. The design problem context posed in the form of a problem situation and constraints (purpose) served as motivation for students to explore a variety of related objects. Attention was drawn to materials and properties, working mechanisms of artefacts, etc. through references to pictures, animations, and video-clips. A wide range of ideas were investigated to help students in designing.

Design exploration: Students worked in groups as they explored design ideas for the artefact to be made. Group members negotiated their ideas through sketches, gestures and talks. Their talks addressed issues of size, material, assembly and functions. They wrote a description of their envisaged product and communicated it to others in the class.

Technical drawings: The design finalised by the group had to be detailed in terms of measurements, proportions and depictions of the envisaged artefact. Students represented their design on paper using perspectives and other representational strategies, including annotations and conventions of dimensions to detail their idea in the technical drawing.

Plan for making: The groups first listed the materials and tools they would require for making the product. They then described and drew a step-by-step account of how they perceived the making process, which we referred to as their *procedural map*. Groups then identified and allocated making sub-tasks to the members.

Communication of design and plan: Groups then communicated their design ideas, materials required and the anticipated process of making to others in the class. The design was thus open for critique by peers and could be modified to accommodate changes.

Making: Implementing plans through actions: Students collaborated using their designs and plans to make the product with available tools and resources. They were free to modify their original designs. The completed product, though conforming broadly to their design, often included changes in material and joints.

Planning and implementing the system (for system of artefacts only): For units that involved a system of artefacts made by different groups, as in case of the puppetry unit, an additional step of "planning and making" was included for system integration. Students after making their artefacts came together to pool in their ideas and plan so that each of those artefacts would function as a system, as in a puppet-show.

Evaluation and reflection: Students were provided with some criteria (like strength, durability, costs, etc.) for evaluating their own product as well as that of others' products. They evolved their own criteria as well, and presented their evaluations to the class. Besides critical thinking, this exercise utilised both language and social skills.

Each of the three units followed a similar sequence and was carried out in every setting over 15 hours spread across 5 days. The trials were conducted between August 2003 and September 2004. Trials of the three units in each setting followed the same sequence as the sequence of development: bag, windmill model and puppetry. The trials for the urban settings were carried out at HBCSE, after the schools hours or in the vacation period of students while trials for the rural sample were carried out in their residential schools and were accommodated in their regular school schedule. Insights gained from one trial helped in refining the lesson plans for the subsequent trials.

The language for researchers' instructions was the same as the medium of instruction in each of the schools. Communication among students and between students and researchers as well as collaboration at several levels of interaction among all participants were integrated into the design of the units.

7.3 Data

Each group maintained a separate portfolio for each of the three D&T units. It included the list of group members and the paper-pencil productions generated during the trials of the unit. The information about self was collected before the first trial and maintained with the researchers. Besides the paper-pencil productions other sources of data included audio-visual recordings in each unit, classroom observations and researchers' logs which included reflective comments and suggestions for refinement.

The portfolios served as a reference for the researchers about the group constitution, and chronology of the members' activities. For students, it was a record of their ideas and actions. The following productions were generated and filed in the group portfolio in each unit:

- Textual descriptions, poems and stories written by group members.
- Activity sheets filled by individual members or the group.
- Students' design drawings in different phases of conceptualisation and articulation of design, in the form of exploratory sketches, technical drawings and procedural maps. These are collectively referred to as *design productions*. An example of design productions of an urban Marathi group in the windmill unit is given in Figure 1.
- Sheets recording the group's evaluation of artefacts - its own and those made by other groups.

The finished artefacts, which were a result of translation of design and plan into a tangible product through the making activity also gave clues about the process and nature of changes made by each group. The different sources of data on student engagement helped researchers organise observations and note the dynamics in the trials of D&T units.

7.4 Analysis

A framework was developed for analysing classroom observations, and another for analysing students' design productions. Analysis of classroom observation was guided by the six aspects of development and trials: students' perceptions, content, classroom interactions, resource use, cognitive aspects, and evaluation of process and product, mentioned at the beginning of this section. Students' design productions were analysed for the influence of the unit, representation strategies used, evidences of visuo-spatial reasoning and knowledge and organisation in students' productions. The two frameworks with supportive evidences from audio-visual vignettes, students' writings, evaluation sheets, and finished products helped infer aspects of cognition in the design and make activity. A discussion of classroom observations will be followed by a section on the findings from an analysis of students' design productions.

8 Classroom observations of D&T unit trials

The following framework was used for analysing the classroom observations.

Students' perceptions and the design exploration: Students' design ideas were shaped by their perceptions of technology, and materials, and their stereotypes of locales and people.

Content knowledge and skills: Analysis of content aspects included students' prior knowledge, their discussions on structure-function relations in artefacts, aspects of language and meaning making, problems and discussions on estimation and measurement.

Teaching-learning and classroom interactions: This aspect explored the effect of specific teaching-learning events planned, analysed observations of class interactions like group dynamics, conflicts and resolution, and students' engagements in activities of estimating, measuring, etc.

Resource use: Observations pertaining to materials and tools that students asked for, explored and used were studied.

Cognition aspects: Observations of reasoning, justification, negotiation, and evidences of visualisation and qualitative thinking in the classroom were used to support the findings from the analysis of design productions.

Students' evaluation: Analysis of students evaluation sheets was supported by the researchers' observation of their comments on procedures, on each others' design productions, products, etc.

The findings from classroom observations for students' perceptions and design exploration, content knowledge and skills, and teaching-learning and classroom interactions are discussed below. Observations pertaining to resource use, cognition and evaluation in this framework are discussed with the findings on design and cognition.

8.1 Students' perceptions and the design exploration

During the design exploration phase in each unit, a discussion was initiated among students about materials and properties. For instance, in the bag-making unit, rural students' discussed the suitability of plastic as a material for bags. Recognising its harmful impact on environment resulted in the avoidance of plastics, which became a negotiated design constraint. Similarly, in the windmill unit, an urban Marathi group arrived at the suitability of using thin wooden sheets in making vanes for their windmill model design.

In the puppetry unit, in all settings, students' consensus on the need for a story with a moral, but wanting to avoid the harshness of terminal violence forced them to modify the chosen story. Students' estimates of cost of an artefact considered the bulk costs of materials used, as well as, the cost of tools. They did not reason about reduced cost per use of reusables, nor did they include costs of time, labour, and marketing.

8.2 Content knowledge and skills

Aspect of content involves the knowledge and skills that students bring to class and those that they acquire by being engaged in the units. It is also about the structure-function relations that students visualised, language and meaning making that happen during negotiations and their knowledge of and familiarity with making estimations and measurement. Making structure-function relations is fundamental to learning biology and is an area of study in science education, for example, in the study of human body systems through the visual and verbal modes (Mathai and Ramadas 2006). Design content is based on making such relations about an imagined artefact.

Students readily talked about objects based on what they had learned in school, from homes and their everyday experiences. Discussions about artefacts among researchers and students were around students' use of terms to describe related objects. For example, students' references to a pin-wheel using different terms triggered a class discussion. Discussions in technology education units afforded opportunities for learning and using context-specific vocabulary.

Students were encouraged to compare and contrast similar objects to investigate structure and function of a windmill model. Designing is about visualising structure-function relations. In the urban English medium students' story for puppetry with three dwarfs, there were inter-group discussions on aspects of age and body size of three dwarf characters. Similarly, urban Marathi students perceived *adivasis* (tribals) as protectors of the forest and conceptualised a tribal character with a spear in hand. This structural attribute prevailed over their own description that the character was a soft-spoken individual.

Students in all settings readily engaged in making paper models of a number of objects such as paper boats, paper planes, camera, etc. The variety of things that students produced of paper in a short span of time exhibited their enthusiasm and skills in paper folding. An urban Marathi girls' group brought to use their local knowledge of strength and the skill of braid for making the handles of their bag.

8.3 Teaching-learning aspects and classroom interactions

A practice exercise on measurements and an exposure to technical drawing conventions were structured to help students visualise and represent the various components of a designed object. Visualisation of relative proportions and estimation of sizes was not initially easy for students. However, once students grasped the conventions of representing lengths and sizes in technical drawings, they used the conventions as well as addressed proportions in their representations.

Visuals, animations and video clips were used to discuss models and working of artefacts and joints in the human body. Line drawings of human figures were used to initiate discussions on body proportions. Socio-cultural stereotypes about human characteristics were also discussed. Students explored their own body movements in groups and filled in a worksheet. In each unit, students handled related artefacts and explored a variety of designs. They handled bags of different materials and for different purposes, different types of pin-wheels and puppets of several kinds – marionettes, glove, stick and finger. They also wrote about the artefact they planned to make.

Classroom interactions between the researchers and students revolved around the design problem context and included a variety of related personal experiences, e.g. visit to a fair. Students negotiated resolutions of conflicts while making design choices, working out details of components, and the process of assembly, resource-sharing, material and tool handling. Group negotiations were often mediated by gestures (of size and shape, of assembly, of motion and expression of joy), paper-pencil sketches and other design productions. Gestures are known to assist and even prompt spatial thinking and development of images in the mind's eye (Athavankar 1999).

9 Discussion of cognition in D&T productions

Students' design productions were analysed using the framework presented in Table 3. This analysis focussed on two major aspects: the cognitive aspects of design, and aspects on evolution of design and socio-cultural features. The category on cognitive aspects analysed the influence of the nature of D&T unit, representations strategies, visuo-spatial reasoning and knowledge and skills in depictions, writings and organisation. Analytical insights for this category come from the area of design thinking and visuospatial reasoning (Lawson 1980/2006, Tversky 2005). The category on aspects of evolution included indications of progression and influence of scoio-cultural features. How design extends into making was understood by a qualitative analysis of the relevant aspects of design during the making activity.

	Aspects studied	Features of design productions observed
	Cognitive aspects of design	
1	Influence of the nature of D&T unit on productions	• Complexity and familiarity of the product • Extent of explorations in the three units
2	Use of representational strategies in design productions	• Perspectives and views • Strategies for depicting details: Use of X-ray drawings; selective abstractions; Enlarged views
3	Visuo-spatial reasoning in design productions	• Quantitative reasoning: Estimations and proportions • Assemblies, joints and reinforcements, use of symmetry, tessellations and repetitions • Analogies in design
4	Knowledge and skills in depictions, writings and their organisation	• Learning to make procedural maps • Students' writings in procedural maps • Materials used and their diversity across the 3 units
	Evolution of design and sociocultural features	
5	Progression within and across D&T units	• Refinement of design ideas within a D&T unit • Progress of students' cognitive activities in design across the three D&T units
6	Socio-cultural features	• Extent of explorations in different settings • Depiction strategies in the 3 settings • Knowledge and organisation • Issues of stability, strength and longevity in designs • Collaborative interactions

Table 3: Aspects of cognition and corresponding indicative features in students' design productions

The analysis of students' design productions gave evidences of cognition in the design and make activity. Supportive evidences came from classroom observations on resource use, cognitive aspects and students' evaluation, and the other productions such as evaluation sheets filled by students, vignettes from audio-visual data and researchers' observations. The findings for the unit on windmill model making have been published (Khunyakari, Mehrotra, Chunawala and Natarajan 2007b).

9.1 Influence of the nature of D&T unit on productions

Several factors influence the design of an artefact. This includes the complexity of an artefact in terms of the number of components and their assembly, familiarity of the artefact envisaged and the context of the problem for which it is a solution. Complexity and familiarity factors varied for the artefacts in the three D&T units.

Familiarity was gauged through students' oral and written communications, as in descriptions of windmill and puppet. Bags of different materials were familiar to students. As a concept, the windmill was familiar to some students and they recollected seeing pictures in books. However, as a mechanical system assembled from several components that served certain purposes, it was the least familiar and the most complex among the three units. Puppetry gave scope for different visualisations of its components, offering more options of design than a bag did. Besides, the different components, the puppets, had to be co-ordinated to produce the working system (puppet show) that served a purpose that was itself negotiable, viz; the message. That is in the case of puppetry, which involved collaborations and complex maneuvers, both the message and the medium were design variables.

Students made more sketches during the design of a less familiar and complex object like windmill, than while designing either a puppet or a bag. The extent of explorations increased with increasing complexity and unfamiliarity of a conceived product. For instance, supernatural characters like *rakshas* (demon), dwarfs and *vanadevi* (forest goddess) were explored with more sketches than were human characters. Machines like the windmill model, involving complex assemblies, elicited a greater extent of explorations than did puppet and bag. The design explorations by an urban Marathi group is a case in point (refer Figure 1).

The extent of explorations on complexity and familiarity extended to the component level as well. For example, explorations of the bag's body, vane structure of the windmill and facial features of a puppet were most explored in the respective units. It has been reported that design explorations ease the cognitive load of designing among professional designers (Bilda and Gero 2005). In another study, the extent of explorations in design

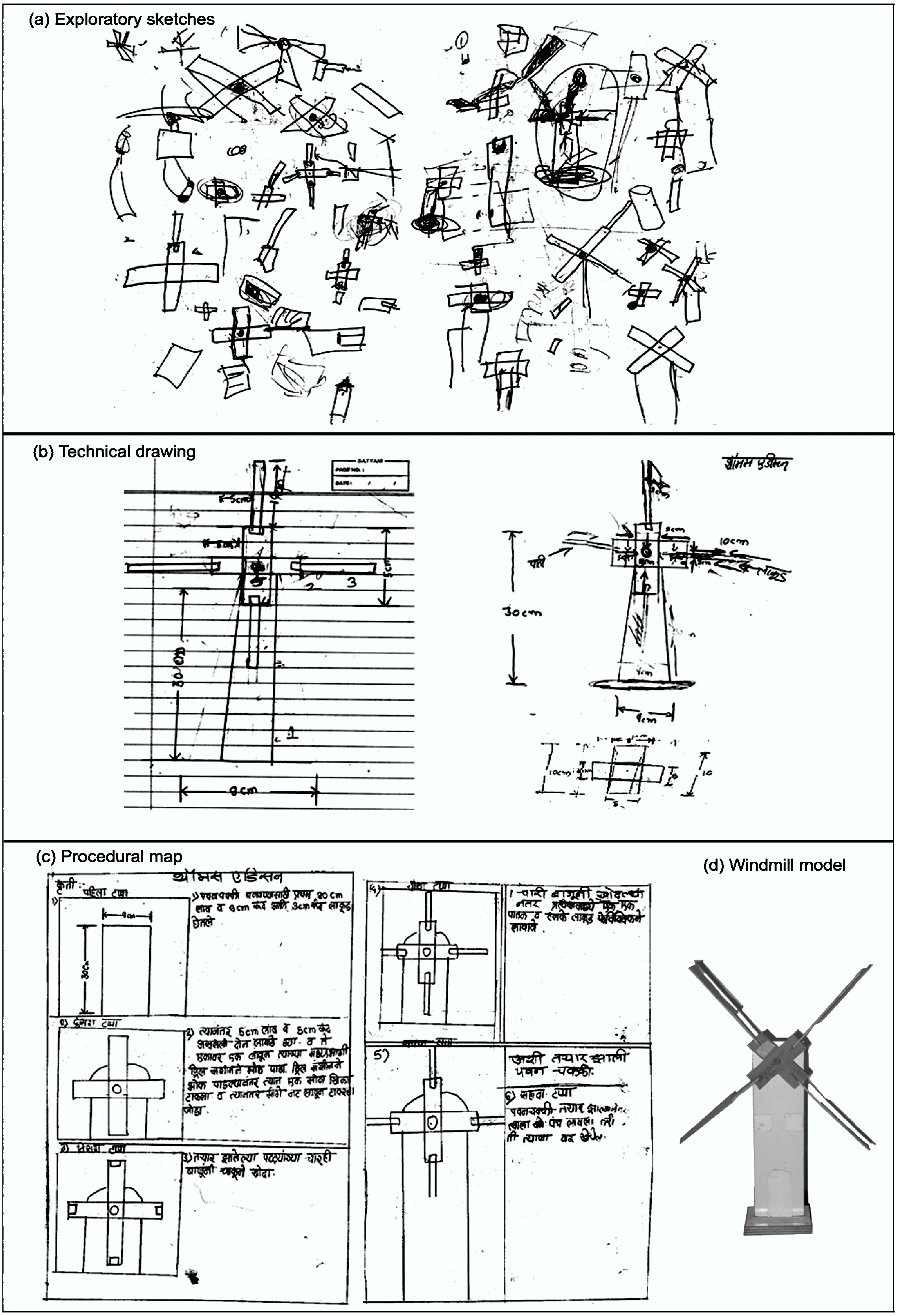

Figure 1: The design productions of an urban Marathi group for their windmill model (a-c), and (d) the finished artefact.

contexts were observed to be greater than in contexts requiring depictions based on problem cues, which in turn showed more explorations than depictions based on textual description (Khunyakari, Chunawala and Natarajan 2007).

9.2 Representation strategies in design productions

One of the challenges for students was to diagrammatically depict on paper the imagined 3-dimensional object. Students without relevant prior training or instruction, spontaneously used a variety of strategies to convey the nuances of their designs: perspectives and view-taking, and detailing through enlarged views, X-ray drawings, selective abstraction and use of graphical symbols and icons.

Perspectives and views

Almost all groups in the three settings opted for a lateral (profile) view for depicting their windmill model, and a front view for their bag and puppet depictions. The multiplicity of components in different planes possibly led students to use views besides the frontal one; views, which would reveal more details of the windmill assembly and occlude fewer parts.

Students also used multiple perspectives in the same drawing. They occasionally used one-point perspective and selective distortions to convey their designs. The Marathi medium students, who were not exposed to technical drawings before the bag-making unit, had difficulty depicting the three dimensions of the bag. They distorted the third dimension, and had problems showing the location and spacing of handles.

Strategies for depicting details

Students devised a variety of techniques to depict the product design and draw attention to components and detail them - inventing icons and graphical symbols on the one hand, and using X-ray drawings, selective abstractions and enlarged views on the other.

Icons of materials (glue-tube) and tools (hammer, scissors) were noted both in exploratory sketches as well as in students' procedural map. Students invented graphical symbols, like hazy lines, circles and over-tracing, to depict components or motion. The diversity of graphical symbols and the number of icons was the highest in the windmill unit. Design of a dynamic mechanical device like windmill afforded scope for generation and use of symbols for different making and assembly actions and for depicting motion.

Students used X-ray drawings in design depictions, especially where assemblies of components were occluded. These were observed more often in the unit on windmill model (23 instances), less in bag designs(11), and least in the puppet depictions (4). Groups sometimes represented some components in a complex assembly as icons or lines in order to facilitate elaboration of other aspects of the assembly. Students used enlarged views, usually a blown-up or zoomed-in view of an assembly, to draw attention to the details.

9.3 Visuo-spatial reasoning in design productions

Students used a variety of modes to conceptualise and negotiate their ideas, as observed in the design productions and audio-visual data: peer talk, gestures, sketches, structural analogies, referents of existing concrete objects around them.

Students went beyond drawings and made 3-D models to help visualise their design better. In the unit on bag making, students spontaneously made models to externalise their product design ideas. In the unit on windmill, the discussion in groups focused on visualisation of parts and assemblies. Besides concrete objects, students also used analogies to arrive at their design. None of the groups in any setting had visualised the weak parts of parts made of paper and cardboard and that they needed to be reinforced. Only during testing did they realise the need to strengthen such parts, as in joints and corners of a bag or the hole in cardboard vanes.

In the puppetry unit, a teaching-learning event of making paper cut-outs or templates of the conceived puppet was introduced prior to the making phase. This helped students visualise their design and the fit between different components while making. Hence this helped reduce wastage of the less abundant resources.

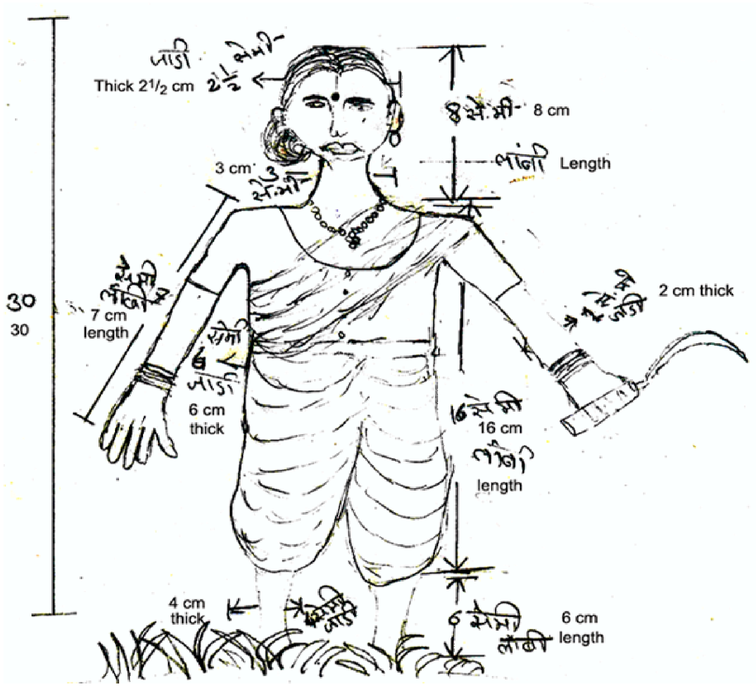

Figure 2: Technical drawing of a female puppet character by a rural Marathi medium group, with only the dimensions and units in Marathi translated to English.

Quantitative reasoning: Estimations and proportions

Design reasoning involves estimating sizes and relative proportions of component parts and assemblies. Quantitative reasoning was indicated in the depiction of dimensions and units, labeling of lengths, and estimates of quantity of materials. Their judgements about proportions of components was especially noticed in their technical drawings as in Figure 2. Students also gestured to indicate sizes and quantities while making design decisions.

Students' estimates of materials were simplistic and did not account for reused materials. Technology involves knowledge about the amount of material that will result in a given size of the finished product in a given design. This knowledge is built through experience until a thumb rule evolves. Students, inexperienced in technological tasks, had difficulty in estimating "making margins" in material quantities, especially in the first unit. In the bag unit, a mixed sex group did not account for the margins for sewing the sides of their bags, resulting in a smaller bag than planned. Once they had experienced these difficulties, they had less difficulty of estimation in later more complex units.

Analogies in design

Design involves analogies, the mapping of knowledge from known domains to the conceived object. Analogies may be visual, involving similarity relations, or conceptual, which involve transformations. The design exploration of vanes for an English medium group began with the sketch of a five-pointed “star” that evolved through several exploratory sketches into a vane structure of two crossed rectangular strips.

Students used objects around them to explain the envisaged structures during negotiations within groups. While discussing the windmill design, an urban Marathi group used a ruler as the tower, and another used two crossed rulers to help develop ideas about their vane structure. Analogies figured even in their texts. In their procedural map descriptions, a rural Marathi group used the analogy of the size of a thick nail to specify the size of a hole in a wooden block. Reasoning by visual analogy is an important strategy in various design problem-solving where ill-structured problems limit the serviceability of rules in the process of problem solving (Goldschmidt 2001).

9.4 Knowledge and skills in depictions, writings and their organisation

Evidences for acquisition of knowledge and skills can be noted in the changes observed either as a result of students’ engagement in a particular activity or exposure to a particular range of artefacts. Students willingly shared in the class the knowledge they had gathered from their investigations outside the class.

There was an improvement in procedural maps from the first to the third unit. Their textual descriptions became more elaborate and they often made references to their illustration in their text. Rural groups’ descriptions in the unit on puppetry were the most elaborate of all procedural maps (among the 3 units, and across the 3 settings).

Verbs describe actions. In the procedural map, which describes through drawing and text the anticipated making, students used several different verbs. In analysing descriptions of working of mechanical objects, Hegarty (2004) classified verbs into two types: Fictive (e.g. to be) and Motion (e.g. rotate, cut). In the procedural map in our study, which are plans of action, there were fewer "fictive" verbs. However, there were a large variety of "motion verbs", which referred to actions of union like *attach, stick, join, sew*, actions leading to physical alterations of materials like *cut, hammer, drill, make a hole/ slit*, and others kinds of action verbs such as *measure, check*.

Developing an understanding of materials and their properties forms one of the main content of design and technology education. Students had opportunities to explore materials in the investigation phase, they conceptualised their designs on the basis of their knowledge about materials and tools and listed them at the end of the designing phase. Students "conversed with materials and tools" – those they had requested and newer, some even unfamiliar, ones that were made available to them – as they engaged in making the product they had designed.

The list of materials and tools given by all the groups in the 3 D&T units was analysed in terms of the number and variety. There were three categories of materials listed and used: main materials, joining materials, and decorative materials.

Students listed a greater variety of materials and tools in the windmill unit (94) than they did in the bag-making (82) and puppetry units (58). The windmill unit offered scope for using different materials not only because it was an assembly of several components, but also because each of its components could be made using one or more of a variety of materials.

The largest number of material items given by students was in the decorative items category in the bag making (19) and puppetry (17) units. These products reflected individual and cultural preferences. The puppets had ornaments (necklace, beads, bangles, armbands), and professional accessories (scythe, spear, crown), while bags were decorated with peacock feather, coloured paper and beads. On the other hand, only 4 decorative materials were listed by 19 groups in the windmill unit.

9.5 Progression within and across the three D&T units

Designing is about progressive refinement of ideas till a satisfactory solution is arrived at. The designs among all groups evolved in two major ways: in terms of shifts in shapes and assembly of components and shifts in material choices. Early in the exploration of design, a number of ideas were negotiated both through verbal and non-verbal communications as well as sketches. Some ideas disappeared from the sketches, while others were refined through the design process, indicating students' evolving ideas and cognitive shifts. An English group started with a composite vane structure in the shape of a five-pointed star; then decided to broaden its vertices and the structure evolved into four truncated pyramidal vanes held together with glue. Similar shape transformations included extensions of vane length, moving from smoothly curved ends to acute vertices.

Students considered possibilities of materials for each component and changed their choices during the process of designing and beyond. In an English group, the vane changed from a flat, truncated pyramidal shape to be made from a sheet (of cardboard or foil) to plastic spoons, and from a tower made of wooden blocks to a bottle filled with pebbles. In an urban Marathi group, a tin container filled with sand replaced the square-like wooden box for a tower.

While there was a progression of design ideas within a design context, it was observed that students also became better at design productions with practice. The design productions in all settings progressively improved in terms of content, clarity and representation. For instance, their procedural maps evolved from the statements of unconnected actions in the procedural map for the bag, the detailed action plan for each of the components in the windmill unit and little assembly description, to greater textual description in the puppetry unit as seen in the procedural maps of an urban Marathi group in Figure 3.

9.6 Socio-cultural influences on design

The extent of explorations, frequency in use of X-ray diagrams, and the details in the descriptions in procedural maps, showed differences between the three settings of Urban

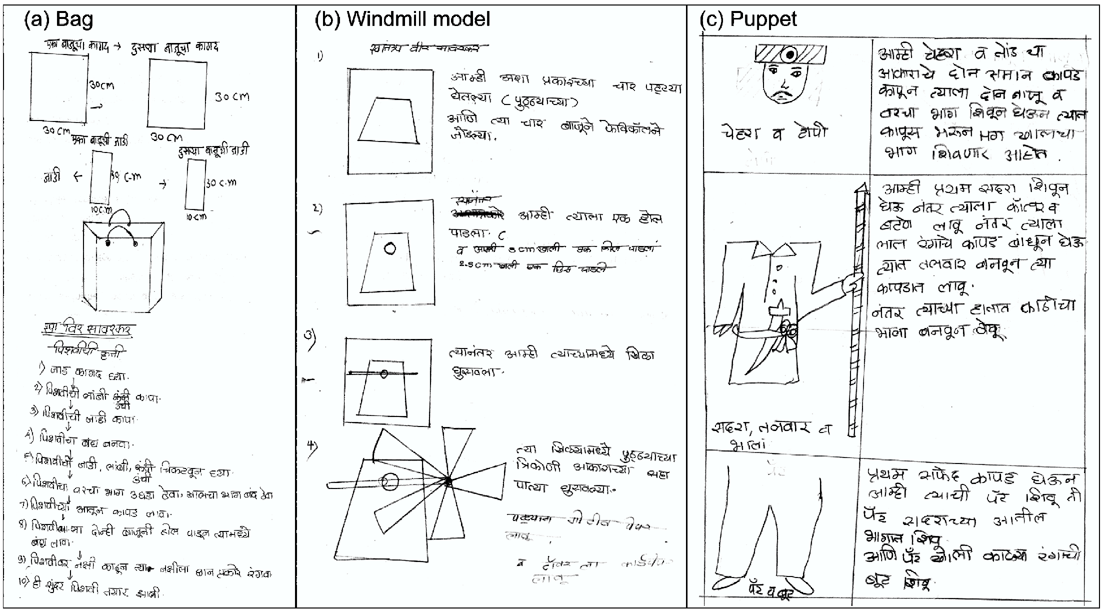

Figure 3: Procedural maps of an urban Marathi group showing increasing textual elaboration from the bag-making unit to the puppetry unit. Only a few steps in the procedural maps of the windmill model and puppet are shown.

English medium, Urban Marathi medium and Rural Marathi medium schools.

Urban Marathi groups made more explorations per group on an average (24) than did the English groups (15). More rural than urban groups' productions had X-ray drawings. Some rural groups used dashed lines for selectively occluding parts in their depictions.

The procedural maps in the three units varied in content and level of details for the urban and rural (tribal) school students. In general, the urban groups had neater illustrations, but briefer descriptions of each step in making. Rural groups had elaborate descriptions for each step. The Marathi medium students, both urban and rural, demarcated the margins, drew boxes, made illustrations and wrote descriptions within it. They were more methodical in their page layout. Urban students listed more number of materials in all three units than did the rural students. The differences were amplified in the unit on windmill model, and least in the puppetry unit.

Students seemed to share some common implicit understanding about material properties, strengths of objects, etc., which were made explicit during the negotiations among the group of designers as they explored and constructed artefacts. Students in different settings used diverse ways to address the issue of physical stability in the windmill unit. The urban groups' designs of towers were more diverse than the designs among the rural groups, who preferred to use wooden slats, with which they were comfortable working. Three of the urban Marathi medium groups preferred a grouted pole design for their towers.

Although there was scope for variations in use of resources, materials and ideas, students seemed to freeze their design ideas early or get fixed to an idea. All but one of the 13 urban groups chose an even number of vanes for their windmill model. On the other hand, half the groups in the rural setting had an odd number of vanes from their explorations to final design drawings. Gluing was the preferred way of joining two parts, especially among the urban students.

The decorative materials and accessories used, more than any other aspect of design and making, reflected the socio-cultural settings of students. Urban students more than rural students used a large variety of religious accessories, like *swastika*, *trishul*, *taaveez* (lucky charm, talisman), sacred thread, etc. The urban students also used western cartoon characters, like *Mickey mouse* and *Pokemon*. Rural students preferred beads, bangles, anklets, etc. and drawings of flowers.

Collaborative completion of design productions within groups was typically observed, in the audio-visuals and in researchers' notes, in urban groups. A sentence started by one member was completed by another, a description by one was simultaneously or sequentially depicted by another. An illustration by a group member was modified by another. These suggest a shared understanding of the design ideas among group members. Collaborations in rural groups, on the other hand, involved collective discussions followed by one member drawing on paper helped by suggestions from others. A detailed analysis of collaboration in the puppetry unit has been reported by Mehrotra, et al (2007).

9.7 Making and cognition

Design conceptualised in and through design productions was translated into a product in the making phase. Students requested for and used the needed materials, tools and other resources. Making of artefacts by the designers themselves involved reflective action and transformation of their own design ideas. Making may be considered as a redesigning phase. Studying the nature of changes in design while being translated into a artefact gave clues to evolution in students' understanding both about design and the artefact. The predominant changes were related to the materials used and fixing of unanticipated problems.

It was observed that while making a windmill model or puppet, though the members were working on different tasks related to the artefact, they did not refer to their common design productions. Yet, their finished products closely resembled their group's design productions. This suggests that once the design was made explicit through representation on paper, the group members shared an understanding of design ideas. Some of these findings with regard to the unit on windmill have been reported earlier (Khunyakari, Mehrotra, Chunawala and Natarajan 2007a). The findings suggest that design thinking once begun continues well beyond the designing phase to the completion and evaluation of the artefact.

10 Conclusions and Implications

The research study involved three parts: (i) a survey of ideas about technology among Class 8 students, (ii) development of three D&T education units through trials among middle school students (Class 6) from urban English medium, urban Marathi medium and rural Marathi medium schools; and (iii) analysis of data collected in the trials for classroom observations of content and pedagogy issues, and cognitive issues in students' design productions. The salient findings from each part is summarised here.

Students' responses to the survey indicated their positive attitude towards technology.

Students' were willing to try out newer technologies, but expressed caution with regard to its consequences in response to introduction of new technologies. The level and extent of technology (high, low) that students perceived in different objects and activities was influenced by whether it was seen as ancient or modern, whether it was static or driven by human/ mechanical or electrical/fuel power, and their association with science, transportation and communication. Activities "outside home" and perceived to need professional/ vocational training in institutions were considered as involving higher technology than "domestic" and "apprentice" (e.g. carpentry, pottery) activities.

Differential levels of exposure seemed to explain some of the urban-rural differences. Interesting among our findings was that more ideas were listed by girls than boys in response to an open-ended question probing their spontaneous ideas related to technology. Gender differences were observed in all settings on the perception of activities, objects and professions as suitable for girls and boys. These differences seemed to confirm existing social stereotypes. Similar stereotypes were evident in students' responses regarding the suitability of certain occupations and activities for either males or females, not both. For example, all indoor tasks were to be assigned to females, and outdoor tasks to males.

Insights gained from the survey helped in developing the three D&T education units. The structure of our D&T units was inspired by the APU model and was modified to suit the Indian context and our research aims. The broader research goal was to study aspects of collaboration and cognition in classroom interactions in the trials of the D&T units through gender and other socio-cultural lenses. The trials conducted among students from three settings aimed to engage students in a broad set of technological practices, including the aspect of design.

The trials of the three D&T units followed a *communication and collaboration centred model*, which engaged students in design problem solving situations. Each unit was a set of loosely structured sequence of activities: Motivation and investigation, Design exploration, Technical drawings, Plan for making, Communication of design and plan, Making, and Evaluation and reflection. The unit on puppetry, which is an example of a technological system, included Planning and implementing the system before Evaluation.

Classroom observations analysed for aspects of content and pedagogy, showed that students benefited in their design when they were given practice activities on estimation and measurements, as well as an exposure to graphicacy skills and conventions of technical drawings. Relations between structure and functions were an important aspect of discussions among students as well as between students and researchers. These interactions were motivated and enriched because the students had handled related artefacts and discussed structural and functional aspects during the investigation phase. The structuring of collaboration and communication in the classroom interaction helped students express their ideas in different modes, like presenting and defending their designs and plans orally, writing poems and descriptions, drawing and gesturing.

Students' design productions showed several aspects of their visuospatial thinking, the most important being that they were able to visualise and conceive the structure of an artefact for a specified function. The more complex and unfamiliar conceived artefact elicited a greater extent of explorations. Students' need to depict varying levels of details guided their choice of views and the selection of strategies, like X-ray drawings and enlarged views. Their sketches showed use of analogies while designing. The number of materials and tools used in windmill unit was more than in the other units. However, decorative materials were much more in the units on bag and puppetry.

Qualitative differences between productions of students from different settings were analysed with no intent of making judgments. It revealed that the Urban Marathi groups had more explorations than did the Urban English or Rural Marathi groups. Rural Marathi students more than urban students had more elaborate writings in their procedural maps. The socio-cultural influences reflected in the choice of decoration materials by students in different settings. Urban students used religious accessories and western cartoon characters whereas the rural students preferred beads, bangles, etc. and drawings of flowers for increasing the aesthetic appeal of their artefacts.

Students collaborated in making the procedural map and followed a sequential or simultaneous completion. Besides, it was often observed that while making the artefact, group members working on different tasks related to the artefact did not refer to their common design productions. Yet, their finished products closely resembled their group's design productions. These suggested a shared understanding of the design ideas among group members.

Students refined their design ideas in the making as well as evaluation phases suggesting that designing pervaded all phases of the *communication and collaboration centred model* for teaching-learning of design and technology.

11 Limitations of our study

Although the study gave valuable insights about the benefits of engaging students in design and technology education, it was largely exploratory. The research, being exploratory, covered a breadth of issues. However, several issues still need to be studied for deeper understanding. Besides, a few students erased their explorations and redrew over their earlier sketches, which limited our access to their design ideas. Some of these ideas were inferred from recordings. The audio-visual data collection was limited by the availability of resources like electricity.

The explorations has opened several possible areas of study like the role of gestures in designing and making activities among naïve designers, the influence of visual and conceptual analogies and the influence of prior exposure to mechanisms and principles in design. Assessment of students' activities, a critical and difficult aspect of introducing D&T education as a school subject, needs to be devised and studied.

A subset of a classroom participated in the study carried out by researchers' team. The units need to be tested in a full-size classroom with one or two teachers. The teacher professional background that will best facilitate D&T education needs to be probed. In addition, a study of naïve, novice and expert designers will help understand cognitive aspects of design better.

References

Assessment of Performance Unit: 1994, Learning through design and technology, *in* F. Banks (ed.), *Teaching technology*, Routledge/The Open University, pp. 59–67.

Athavankar, U. A.: 1999, Gestures, mental imagery and spatial reasoning, *in* J. S. Gero and B. Tversky (eds), *Visual and spatial reasoning in design*, Key Centre of Design Computing and Cognition, University of Sydney, pp. 103–128.

Barlex, D.: 2005, The centrality of designing — an emerging realisation from three curriculum projects, *Technology education and research: Twenty years in retrospect – Proceedings PATT-15 Conference*, pp. 1–9.

Berkner, L. V. and Kranzberg, M.: 1969, Industry and technology, *in* R. J. Feldman (ed.), *Cowles encyclopedia of science, industry and technology*, Cowles Book Company, Inc., New York.

Bilda, Z. and Gero, J. S.: 2005, Does sketching off-load visuo-spatial working memory?, *in* J. S. Gero and N. Bonnardel (eds), *Studying designers'05*, Key Centre of Design Computing and Cognition, University of Sydney, pp. 144–159.

Choksi, B., Chunawala, S. and Natarajan, C.: 2006, Technology education as a school subject in the Indian context, *in* K. S. Volk (ed.), *Articulating technology education in a global community*, Hong Kong Technology Education Association and The Hong Kong Polytechnic University, pp. 280–290.

Chunawala, S.: 1987, A study of the occupational choices of first generation learners, *Journal of Education and Social Change* **1**(3), 52–64.

de Miranda, M. A.: 2004, The grounding of a discipline: Cognition and instruction in technology education, *International Journal of Technology and Design Education* **14**, 61–77.

de Vries, M. J.: 1992, Design methodological lessons for technology educators, *in* E. A. Bame and W. E. J. Dugger (eds), *Technology education: A global perspective — ITEA-PATT International Conference Proceedings*, International Technology Education Association, Reston, USA, pp. 99–108.

de Vries, M. J.: 2005, *Teaching about technology: An introduction to the philosophy of technology for non-philosophers*, Vol. 27 of *Science & Technology Education Library*, Springer, The Netherlands.

Goldschmidt, G.: 2001, Visual analogy – a strategy for design reasoning and learning, *in* C. Eastman, M. McCracken and W. Newstetter (eds), *Design knowing and learning: cognition in design education*, Elsevier Science, Amsterdam, pp. 199–219.

Hegarty, M.: 2004, Mechanical reasoning by mental simulation, *Trends in Cognitive Sciences* **8**(6), 280–285.

Hennessy, S. and Murphy, P.: 1999, The potential for collaborative problem solving in design and technology, *International Journal of Technology and Design Education* **9**, 1–36.

ITEA: 2007, Standards for technological literacy: Content for the study of technology. International Technology Education Association (ITEA), Virginia, USA.

Khunyakari, R., Chunawala, S. and Natarajan, C.: 2007, Comparison of depictions by middle school students elicited in different contexts, *in* J. R. Dakers, W. J. Dow and M. J. de Vries (eds), *Teaching and learning technological literacy in the classroom: Proceedings Pupils' Attitudes Towards Technology (PATT 18) Conference*, Faculty of Education, University of Glasgow, pp. 392–399.

Khunyakari, R., Mehrotra, S., Chunawala, S. and Natarajan, C.: 2007a, Cognition in action in design and technology units among middle school students, *in* C. Natarajan and B. Choksi (eds), *Proceedings epiSTEME-2: International Conference to review research on Science, Technology and Mathematics Education*, Homi Bhabha Centre for Science Education, TIFR, Mumbai, India, MacMillan India Ltd., pp. 126–131.

Khunyakari, R., Mehrotra, S., Chunawala, S. and Natarajan, C.: 2007b, Design and technology productions among middle school students: An Indian experience, *International Journal of Technology and Design Education* **17**, 5–22.

Khunyakari, R., Mehrotra, S., Natarajan, C. and Chunawala, S.: 2003, Ideas about "technology" among middle school students in Mumbai — preliminary analysis of a survey, *in* P. V. Dias (ed.), *Social production of knowledge through diversity of expressive modes, multiple literacies and bi(multi)lingual relationships: International Symposium*, Multilingualism Network, J. P. Naik Centre for Education and Development, Indian Institute of Education, Pune.

Khunyakari, R., Mehrotra, S., Natarajan, C. and Chunawala, S.: 2006, Designing design tasks for Indian classrooms, *in* M. de Vries and I. Mottier (eds), *Research for standards-based technology education: Proceedings PATT-16 Conference*, International Technology Education Association, Baltimore, USA, pp. 20–34.

Kimbell, R. and Stables, K.: 2007, *Researching design learning: Issues and findings from two decades of research and development*, Vol. 34 of *Science and Technology education library*, Springer, chapter Learning and teaching: A philosophical position, pp. 29–44.

Kimbell, R., Stables, K. and Green, R. (eds): 1996, *Understanding practice in design and technology*, Open University Press, Buckingham.

Lawson, B.: 1980/2006, *How designers think: The design process demystified*, 4th edn, Architectural Press/Elsevier Ltd., Amsterdam.

Mathai, S. and Ramadas, J.: 2006, The visual and verbal as modes to express understanding of the human body, *in* D. Barker-Plummer, R. Cox and N. Swoboda (eds), *Diagrammatic representation and inference, LNAI 4045*, Springer-Verlag, Berlin, pp. 173–175. http://www.springerlink.com/content/4255p832277j5v34/.

McCormick, R.: 1997, Conceptual and procedural knowledge, *International Journal of Technology and Design Education* **7**, 141–159.

Mehrotra, S., Khunyakari, R., Chunawala, S. and Natarajan, C.: 2003, Using posters to understand students' ideas about science and technology, *Technical Report No.I (02-03)*, Homi Bhabha Centre for Science Education, Tata Institute of Fundamental Research, Mumbai, India.

Mehrotra, S., Khunyakari, R., Natarajan, C. and Chunawala, S.: 2007, Collaborative learning in technology education: D&T unit on puppetry in different Indian socio-cultural contexts, *International Journal of Technology and Design Education* . DOI 10.1007/s10798-007-9037-1.

Mitcham, C.: 1994, *Thinking through technology: The path between engineering and philosophy*, The University of Chicago Press.

Oxman, R.: 2001, The mind in design: A conceptual framework for cognition in design education, *in* C. Eastman, M. McCracken and W. Newstetter (eds), *Design knowing and learning: Cognition in design education*, Elsevier, Oxford, UK, pp. 269–295.

Rajput, J. S., Pant, S. C. and Subramaniam, K. B.: 1990, Pupils' attitudes towards technology in rural schools in India, *in* R. Stryjski and H. Szydkauski (eds), *Report of the PATT-conference in Poland 1990*, Vol. 2, Eindhoven University of Technology, Eindhoven, pp. 38–54.

Roberts, P.: 1994, The place of design in technology education, *in* D. Layton (ed.), *Innovations in science and technology education*, UNESCO Publishing, France, pp. 171–179.

Rowell, P. M.: 2004, Developing technological stance: Children's learning in technology education, *International Journal of Technology and Design Education* **14**, 45–59.

Tversky, B.: 2005, Visuospatial reasoning, *in* K. J. Holyoak and R. G. Morrison (eds), *The Cambridge handbook of thinking and reasoning*, Cambridge University Press, pp. 209–240.

Williams, J. P.: 2000, Design: The only methodology of technology?, *Journal of Technology Education* **11**(2), 48–60.

Zuga, K. F.: 2004, Improving technology education research on cognition, *International Journal of Technology and Design Education* **14**, 79–87.