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ORIGINAL PAPER

# Design and technology productions among middle school students: an Indian experience

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**Abstract** The focus of this paper is students' design productions as they engaged in designing and making a windmill model to lift a given weight. This work is part of a project on the development of design and technology (D&T) education units and its trials among Indian middle school students (Grade 6, age 11–14 years) in different socio-cultural settings. Since D&T is not a part of the Indian school curriculum, the students had no earlier experience of design. Our trials included an exploratory phase followed by groups of students producing technical drawings and a plan for the making action (procedural map) before engaging in making the windmill model. The paper presents findings from a qualitative analysis of urban and rural students' pencil and paper productions, complemented by observations from video recordings of the collaborative engagement of these naïve designers. Students used graphical symbols, analogical, spatial and functional reasoning in their design activities. Choice of materials and tools, the nature of exploratory sketches, variety in design and attentions to issues of stability showed differences between the urban and rural groups. Some potential implications of D&T units for classroom learning have also been discussed.

**Keywords** Cognition · Design and technology education · Design productions · Middle school students

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## Drawings, design and cognition

Drawings help mediate and externalise thoughts and ideas. They have been used by psychologists as diagnostic tools and for studying developmental sequence in the early stages of learning (Goodnow, 1977). Drawing is a means of expression, exploration and discovery. It is a multipurpose tool for enquiry, comprehension and communication (Adams, 2002); for organising and representing ideas; for analogical (Gentner, Holyoak, & Kokinov, 2001), and visuo-spatial (Tversky, 2002) reasoning; and a recording medium (Hope, 2000). Drawing as a socio-cultural activity is reflected in symbolic and cultural conventions or resource preferences in productions (Anning, 1997).

Drawing, which plays an important role in design, is at the heart of technological activities. Practitioners of technology, modern and pre-modern, ‘‘read’’ drawings because they understand and share symbol conventions (Do and Gross, 1996). Drawings reveal contexts and indicate the intentions of design. Design drawing is an external representation that helps in problem solving and generating ideas (Ullman, Wood, & Craig, 1990; Cross, 1984). While advocating an approach to teaching and learning drawings, Edwards (1992) has claimed that drawing can be a potent problem-solving aid for both children and adults. Anning (1997) has emphasised the role of graphicacy, the use of drawings in representing ideas or objects, as a tool for learning and recording thinking in classrooms. She believes that people are socialised into working within the modes of graphicacy each discipline demands of them. Many designers, engineers and practitioners in technology education have also emphasised the richness of design drawings as the non-verbal language of technology.

Designing is an interaction between the mind and hand (Kimbell, Stables, & Green, 1996). Design thinking is concerned with form as well as function, and includes visual and spatial reasoning. Attempts to understand the process of design through studies with professional designers like architects and engineers have revealed interesting facets of design activity, like the ill-defined nature of design problems, use of primary generators in early designing and the use of shared conventions among designers (Cross, 1984). These studies have broadened the understanding of design process in general, and have given valuable insights for design in school education.

Cross (1982) emphasises that design is analogous to, and distinct from, the two cultures of the ‘‘humanities’’ and the ‘‘sciences’’. He advocates design as a coherent academic discipline in general education, which need not be merely a preparation for a career or for productive skills for the industry, but can enhance and develop students' intrinsic cognitive processes, values and abilities (Cross, 1982; Roberts, 1994). Students' verbal and non-verbal representations, as they explore and evaluate alternative ideas of conceived artefact, process or system, give us clues about their understanding and its progression. This paper reports our attempt to study students' design ideas as seen through their productions in design and technology (D&T) units.

### Design and technology units

There has been considerable research in D&T education on school students from pre-primary to secondary school levels. Research studies have used drawings and interviews to understand children's ideas of objects, their structure and functions.

Senesi (2000a, b) studied individual French pre-primary school children (aged 3–6 years) and analysed their drawings and utterances about artefacts like scissors, before and after allowing them to handle and make the artefacts. The studies revealed that after the construction activity, there was significant progress in students' concepts and knowledge of the origin of artefacts and of tool use.

Hope (2000) studied the processes involved in drawing for design and the way in which young children (aged 5–9) used drawings to aid their thinking about processes that they were planning to make. Some studies have probed students' progression in D&T tasks (Solomon and Hall, 1996). Rowell (2004) has highlighted the benefits of collaboration while explaining her ideas of the technological stance in education.

Studies have been reported on Indian school students' conceptions of technology (Mehrotra, Khunyakari, Chunawala, & Natarajan, 2003; Bhattacharyya, 2004). However, there have been no studies on Indian school students' performance in design and technology tasks. Technology education at school level in India has had a confused identity: operating as applied science, socially useful productive work, vocational education or a pot-pourri of all. School science emphasises theoretical principles and experiments demonstrated primarily by the teacher. Science and technology literacy (STL) addressed in the National Curriculum Framework (NCERT, 2000) merely incorporates technology and society as appendages to science. Policy makers have envisaged *work experience* as making socially useful objects in large numbers, and in the process, gaining skills while following recipes. Vocational education is geared solely towards developing skills for employment, its syllabi being often outmoded giving no scope to students for innovation of process or product. There have been no attempts so far to introduce D&T in school education in India, though it is being introduced the world over as a separate subject in school curricula.

The Homi Bhabha Centre for Science Education (HBCSE), a national centre of the Tata Institute of Fundamental Research (TIFR), is a premier institution in India for research and development in science and mathematics education. Its activities span science popularisation, development of science and mathematics curricula, in-service teacher training programmes and a graduate studies programme leading to a doctorate degree in science education. The research at HBCSE on D&T education is an initiative to study the possibility of introducing D&T in Indian classrooms. We envisage developing D&T units with an important role for design, and the structure of our D&T units is inspired by the Assessment of Performance Units (APU) model (Kimbell et al., 1996).

## Methodology

Three D&T units were developed and their trials were conducted among students from three different schools. The units were: making a bag to carry a few books, making a windmill model that can lift a given weight and making puppets and collectively staging a puppet show. About 70 middle school students from one rural and two urban schools participated in the study.

During the trial of each unit, students worked in groups on several tasks. They contextualised and negotiated the problem, investigated potential solutions and made exploratory sketches. They made technical drawings, including details of dimensions and list of required materials, and drew up a plan for making (procedural map). They distributed the tasks among group members, communicated the design and the making plan to peers. They made their products and finally each group evaluated its own and others' products.

## Objectives of the present study

This paper focuses on the design productions in the D&T unit on making a windmill model to lift a given weight. The objectives included exploring the productions for evidence of cognitive aspects like functional, spatial and analogical reasoning and planning. The paper presents a qualitative comparison of students across different socio-cultural settings in their use of material resources, in the distribution of tasks among group members and in the evolution of their ideas of assembly of parts in the windmill, as they carried out the design tasks in a collaborative learning environment.

## Sample

The samples for the study came from three distinct socio-cultural settings with two different media of instruction: an urban Marathi medium school (UM), an urban English medium school (UE) and a rural (or tribal) Marathi medium school (RM). Marathi is the official language of the State of Maharashtra, whose capital is Mumbai. There are more than 60 million native speakers of this language in the State and the majority of Government-run schools have Marathi as the medium of instruction. Marathi is one of the Indo-Aryan languages, which uses the Devanāgari script and derives its grammar and syntax from Sanskrit language.

About 25 students from each school, with near equal proportion of boys and girls from Grade 6 (age 11–14 years) were chosen from among the students who volunteered. In addition to the socio-cultural criteria, proximity of schools to researchers' institution and a rapport with the school management also influenced the selection of schools.

The selected rural school was a residential school (*Ashramshaala*) run by the Tribal Welfare Department of the Government of Maharashtra State, in an effort to provide educational opportunities to socio-economically underprivileged tribes (indigenous people normally living in hamlets at the edge of forests). *Ashramshaalas* provide students with the minimal needs of shelter, daily food, uniforms and books. In the *Ashramshaala* selected for the study, classrooms doubled up as living quarters after school. The school had electricity at best for a few hours a day and students used a hand-pump to pump up limited amount of groundwater. The spaces around the school and nearby villages located among green hills had far fewer technological artefacts than do urban spaces. The two urban schools had far more facilities like library, laboratory, sports equipment, furniture and toilets with water on taps. Besides, they also had easy access to a variety of sources of information, both print and other media. Most UE students had access to a computer and an internet facility.

## Intervention

Each D&T unit was carried out in every setting over 15 h spread across 5 days. The students were requested to form groups of 3–4 members. In each setting there were 2 groups of girls, 2 groups of boys and 2 mixed sex (boys and girls) groups.

The language for researchers' instructions was the same as the medium of instruction in each of the schools. The home language of most RM and UM students was a variant of Marathi. The UE students came from a variety of home languages; none from English speaking homes. Being from the vicinity and similar socio-cultural settings as the researchers, the urban (UE and UM) students soon became friendly with the researchers and familiar with their methods. For the RM students, two preparatory sessions that included numerous activities like playing games, categorising leaves, describing the forest and designing a postage stamp preceded the D&T unit trials. Video cameras and audio tapes were also used during these activities to help students get comfortable with the presence of such equipment.

The second D&T unit among the three units was designing and making a windmill model that can lift a given weight. The toy windmill (pin-wheel or *firki*), with which all students were familiar, was used to initiate the discussion on windmills. Students from all settings had heard and seen pictures of windmills in their science textbooks. The goal of the D&T unit was contextualised through a story narrated to the students: the story of a village farmer, his wife and their two children. *The family used groundwater for irrigation, and found it difficult to lift water in the absence of electric power. The children visited a village fair, bought a toy windmill and played with it. They discovered that it could lift a feather and used the idea to devise a way to lift groundwater: they made a windmill model.*

Students made a pin-wheel using pin, paper and drinking straw. They explored it and drew its lateral and frontal views. Structure and function of windmill parts were discussed. Students were shown photographs of a variety of historical and current windmills used for different purposes. They were encouraged to write a description or a poem on windmills. Students were also exposed to the role and significance of technical drawings following the convention of leaders, arrows and end lines.

Students then explored the design of the windmill that their group would make. They did so through discussions within the group and exploratory sketches drawn on sheets of paper individually or collectively. When each group had agreed upon a design, they drew labelled technical drawings and listed the materials needed for making the windmill. Students anticipated the procedure for making and wrote how they might distribute the making tasks within the group. Each group discussed their group's design and making plans with other groups. Inputs from other groups sometimes led to modifications of their design. Each group was then given the materials they had asked for and the groups became immersed in making their windmill models. Groups tested the working of their product and evaluated it. They also evaluated others' products and discussed their evaluations with all groups in a setting.

## Data collection

The activities generated unstructured and semi-structured individual and collective productions—sketches, technical drawings, procedural maps, written records, oral presentations and gestures—and structured productions like evaluation sheets. The productions through multiple modes of expression were recorded by students on paper. Researchers had audio and video recordings as well as daily records of classroom activities written as logs. These served as inputs for analysis.

## Analysis of design productions

We explore here the cognitive aspects of drawings in a collaborative learning environment of the D&T unit: use of material resources, functional reasoning, planning and distribution of tasks among group members, etc. The analysis of pencil and paper productions of middle school students (naïve designers) in this study is with respect to the designing of a windmill model, how the design productions compared across the three different socio-cultural settings and how the design evolved. The analysis focuses on the diversity and speciality of each setting rather than on giving an overall rating to each. The productions considered for analysis here are exploratory sketches, technical drawings and procedural maps.

The design productions of the students were constrained by the nature of task, medium of representation and structural requirements of the model. A windmill model is a complex artefact involving the essential components of tower, axle and vanes, and their assembly. The tower provides anchor for the vanes at a height where they can tap the wind. The vane assembly is attached to one end of a freely moving axle, whose movement can be used in a variety of ways. The nacelle, a box covering the axle machinery, in simple models enables free movement of the axle.

Representations of these components were analysed according to a set of themes, like functional reasoning, use of graphical symbols, spatial reasoning, analogical reasoning, materials and tools and evolution of design from explorations through procedural maps. Spatial reasoning concerned the relative placement of components. Functional reasoning included students making quantitative estimates of sizes and proportions, representation of 3-D object ideas on 2-D paper, and using dimensions and units following conventions of using leaders, arrows and end lines.

General observations of the productions, namely, the exploratory sketches, technical drawings and procedural maps, in each socio-cultural setting (UM, UE and RM) are presented in the paper. One group from each setting has been chosen here as a representative (typical) of the entire setting. This choice has been made on the basis of the features of their productions. For example, when most of the groups in a setting had extensive exploratory sketches, the group chosen had these features. Referred to as TUM, TUE and TRM, productions from these three typical groups are used to exemplify the comparisons across the three settings UM, UE and RM.

### Exploratory sketches

In general the urban groups (UE, UM) made sketches all over the sheet of paper and depicted all the structural components of their windmill model. The urban groups focussed on the vane assembly (65 out of 108 unambiguous exploratory sketches for UM; and 22 out of 58 for UE) and explored less often the details and assembly of the tower (17 for UM, 13 for UE) and axle (2 for UM, 8 for UE). The designs of four groups in the urban settings evolved through the use of analogies as observed in their sketches and video records. From the RM groups, on the other hand, we had fewer records of their exploratory sketches (total of 21 explorations, several partially erased, in 6 groups). The rural groups used their resources sparingly, including the paper provided to them. They erased and drew or wrote on the same sheet of paper.

*Functional reasoning*

The TUE group omitted irrelevant details and abstracted important features, e.g. drawing iconic vanes on an axle mounted on iconic supports as they focussed on the assembly of vanes and tower poles, as seen in Fig. 1a. The TUM group had problems depicting on a 2-D sheet of paper their two flat mutually perpendicular vane segments. In their composite vanes and other assemblies, they sought to accommodate multiple perspectives in the same drawing.

*Graphical symbols*

Students invented and used similar symbols to represent different functional attributes. The TUM group used circular lines around vanes to suggest motion and also to represent a disc or a base-like structure at the foot of the tower. This was also seen in their technical drawing (Fig. 2b). The TUE group drew a circle around a triangle to isolate a single vane from other drawings on the sheet.

*Analogical reasoning*

The TUE group's sketches evolved from a five-pointed star into four vanes, the vertices becoming the broader ends of vanes as depicted in Fig. 1b. The video records of TUM groups showed the use of concrete visual-spatial analogies: rulers to explain arrangement of vanes, a pencil to visualise axle, and ruler resting vertically on the table to show the tower. Students also used analogies to describe materials needed (e.g. a wire as thick as a nail). Students used analogies from their immediate surroundings in all phases of design. The UE groups, for instance, derived the idea for their tower design from artefacts in the room (camera stand, tripod stand).

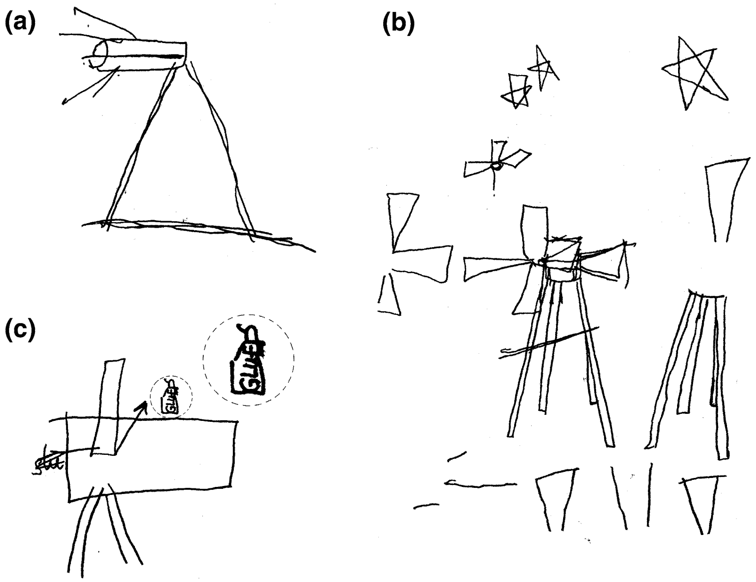


**Fig. 1** In TUE design explorations, (**a**) iconic representation of tower poles and vanes, (**b**) evolution through analogical reasoning and (**c**) depiction of the label "glue"

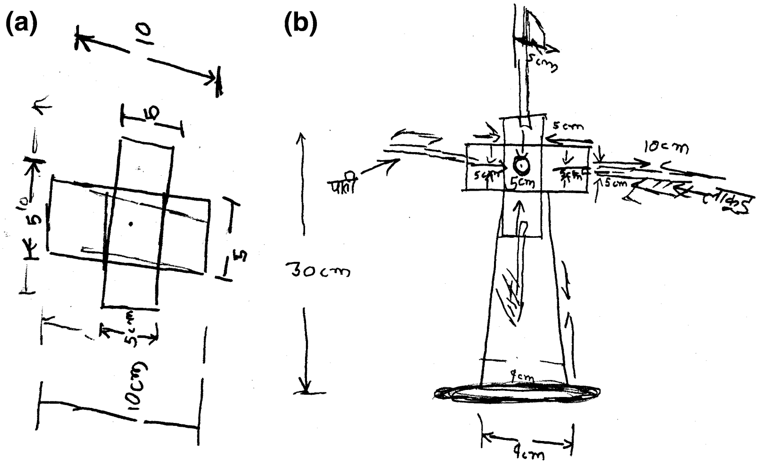

**Fig. 2** Technical drawing of TUM showing (**a**) an exploded view of the vane assembly, and (**b**) 3-D composite vanes

*Materials and tools*

The urban groups depicted the use of materials and tools in the productions even at the exploration stage. For example, the label "glue" was shown at the point of attachment of a vertical column to a rectangular sheet by the TUE group (see inset in Fig. 1c). The use of knife action by TUM group to show slots was seen in the video. Instances such as these suggest that the naïve designers were engaged in a "reflective conversation with materials" (Schön, 1983).

Technical drawings

The tower design and the assembly of vanes to the axle posed a challenge to students from all settings. Several groups from the different settings solved the problem by analogical reasoning. Though all groups were given an exposure to technical drawing conventions, more groups among the UE (4 out of 6) followed the conventions of depicting dimensions. The UE groups had the benefit of a practice task on conventions.

*Functional reasoning*

The TRM group showed dimensions of their components using arrows but omitted the leaders. While the TUM group drew exploded views of the vanes (Fig. 2a) and other parts in their technical drawings, TUE and TRM did not draw any exploded views. Every setting had at least one group that drew exploded views. The TUM group showed dimensions in all design productions beginning with the technical drawings and used the convention of leaders, arrows and end lines (Fig. 3a).

In attempting to indicate 3-D objects on a 2-D sheet, the TUE group showed the width of their tower by differences in the length and base position of the front and back poles of the tower and the tower roof by a parallelogram (Fig. 3b). They had similar depictions in their explorations (Fig. 1b). Their drawings had several

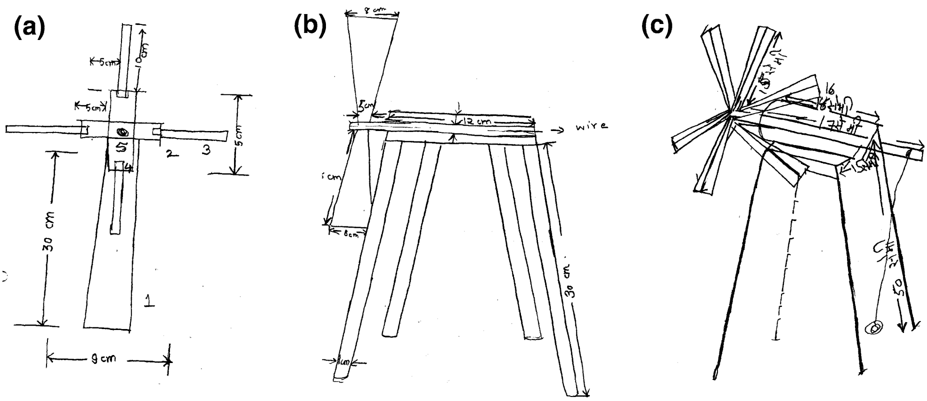

**Fig. 3** Technical drawings of typical groups in the three settings—(**a**) TUM shows dimensions using conventions and numbering of parts to refer to steps in their procedural map; (**b**) TUE uses one-point lateral perspective with selective occlusion of a vane, a label (wire), dimensions with conventions; and (**c**) TRM shows multiple perspectives, X-ray depictions of vane and axle, selective abstraction of tower poles, and absence of end-lines in dimensions

instances of occlusion of parts as well as a few X-ray drawings: e.g. a wire was shown passing through the axle (Fig. 1a). In all three settings, the groups tackled the problem of translation of 3-D objects to 2-D paper by depicting all parts in a single drawing with multiple views. A few X-ray drawings were observed in the drawings of most groups in all settings. They were more often seen in the productions of the RM (5 out of 6) and UM (4 out of 7), as shown in Fig. 3c, than in the UE (1 out of 6) groups. Anning (1997) reported that after 9 years of age, students do not make X-ray drawings. The presence of such drawings in our sample may have been due to a lack of exposure to the graphical world and practice in design.

The TRM group had fewer labels and annotations in their technical drawings, which they often made up for by their elaborate materials list. An unlabelled object depicted on the tower roof was clarified in their material list as a cylinder. Their material list included a few tools, but no details of dimensions.

### *Spatial reasoning*

Trying to represent the composite structure of the windmill model caused a spatial conflict. The TUM group depicted their composite vanes, consisting of two mutually orthogonal segments, as the frontal view of both the vane segments. Their drawing skills initially constrained them to the choice of front view for depiction, which conflicted with their need to represent the assembly in 3-D that they clearly saw in their "mind's eye". The best they managed was something that looked like a flag as seen in Fig. 2b, which was resolved by the correct frontal views in subsequent drawings, as seen in Fig. 3a.

### Procedural maps

Groups from all settings neatly organised their procedural maps, with steps ranging from 4 to 11 in number (average number of steps for UM setting was 5 per group, RM had 6 and UE had 7). Each step had a drawing, usually framed by a box, accompanied by a description, either positioned alongside or at the bottom of the box. Most urban groups (11 out of 13) numbered the steps and made explicit reference to the illustrations in the text. For example, one of the steps in the procedural map of a mixed UE group was ‘‘Fold the blades and cut them as shown’’. The UE groups tended to use active voice in the text for describing the steps in making. In the case of some RM groups, the drawings were accompanied by texts in the passive voice suggesting completed tasks, rather than prescription for making. For example, ‘‘Then the four pieces were placed vertically to form the tower’’.

In general, the drawings in the procedural maps of all groups were sketchier than their technical drawings, with fewer technical details and less accuracy. The UE groups used referent labels in their maps and showed icons of tools (like hammers and scissors) and making actions through symbols more often (23 instances from 6 groups) than did groups in the RM (11 in 6 groups) and UM (10 in 7 groups) settings. The UE groups’ drawings corresponded closely with the crisp directions written alongside.

Of all the settings, the UE groups were most likely to have been exposed to manuals and do-it-yourself kits. Their descriptions included measurement details and dimensions of components. Stability and rigidity of their models were issues considered more often by the RM and UM groups and less often by the UE groups. This concern was reflected in their designs by the choice of materials. For example, the RM and UM groups used plastic caps, small pieces of pipe, wires, metal rings, erasers or foil to retain the vanes on the axle and prevent them from coming loose. But the UE relied on materials like styrofoam piece, cellotape and glue to keep the vanes in position. Most RM groups (5 out of 6) reinforced their 4-poled towers with wooden strips across adjacent poles to prevent wobble, while most UM groups (4 out of 7) used metal or plastic containers filled with sand to make their windmill tower stable.

### *Functional reasoning*

Students had difficulty representing dimensions of composite parts. There were indications of the problem even in the TUM group’s technical drawing, which showed a vane in three segments of 5 cm each, while the vane was described to be 10 cm long (Fig. 2a) or 5 cm (Fig. 3a). There were fewer dimensioned drawings in the UM (a total of 7 among 7 groups) and UE (16 among 6 groups) settings than in the RM setting (21 among 6 groups). The UE groups chose to refer to dimensions in some of their textual descriptions. The plan of the TRM group was detailed and included measuring, marking and cutting actions in the drawing and description. Though they showed the measuring device (ruler) and the markings on it, the markings as well as the alignment of the ruler for measuring were incorrect (inset Fig. 4a). The group selectively showed occlusion and use of dashed lines (Fig. 4b).

### *Spatial reasoning*

In their drawings and descriptions, the UM and RM groups indicated relative positions of components. They described spatial arrangement as ‘‘horizontal’’ and

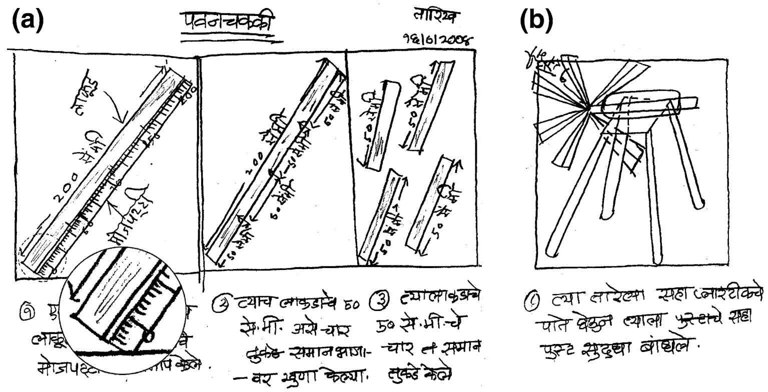


**Fig. 4** Parts of a procedural map by TRM group showing (**a**) detailed markings on a measuring device and (**b**) occlusion and X-ray drawing

"vertical". UM groups described components as "cylinder shaped", and referred to proportions like "equal parts" and "a hole the size of a nail". In its procedural map, the TUE group showed the vanes attached to the shaft instead of the axle. It also fixed this shaft to the tower not realising that these two steps would prevent the vanes from moving with the wind. Besides, the shaft was shown wholly within the tower roof, which would have been practically impossible to make.

*Materials and tools*

All UM and RM groups specified materials required and even their quality; only 7 out of the 13 groups gave estimates of quantity. The UE groups just listed names of materials with neither estimates of quantity nor quality. Preferences of materials reflected the settings and exposure of students. The urban groups requested for and used materials like cardboard, styrofoam, wooden sticks, metal foils and containers, wood and plastic for the vane and tower components of their windmill model. In contrast, the rural groups made these components of mostly wood and metal foils. UM and RM groups indicated relative dimensions of objects to clarify their material requirements; e.g. "a nut of the size of the screw" by TUM group, and "a wire as thick as a nail" by TRM group. For joining parts including wooden ones and metal foils, the urban groups preferred to use adhesives, sticking tapes and varieties of glue, while the rural groups preferred hammer and nails and a kind of easily available glue. Tools were included in the material list by all the groups in the UM setting. However, in the UE and RM settings, only half the groups did so, while the remaining half of the groups included tools in the texts of their procedural maps later.

*Work distribution*

The work was distributed among the members of RM groups in terms of specific steps, rather than in terms of composite tasks as done by the urban groups. The RM groups distributed cutting, sticking or joining to different members, while the urban groups (UE and UM) assigned the making of vanes, tower or assembly to their members. As they did in their procedural maps, the TRM group's assignment of work was also in terms of completed tasks rather than tasks to be executed. For example, ''A wooden stick of length 200 cm measured and cut into 4 equal parts of 50 cm each was done by K'' (K refers to a girl). Another example: ''Then, the job of piercing...was done by L'' (L refers to a boy).

### Evolution

All groups irrespective of their socio-cultural setting showed evolution in the components of their windmill model starting from their earliest design ideas in exploratory sketches through technical drawings and procedural map. We looked at what changed in students' drawings as they collaboratively negotiated ideas from the exploration phase to procedural maps and then to making the product. For instance, the vane structures in several urban groups (9 out of 13) evolved from being triangles to rectangles to more complex shapes, like truncated and right angled triangles or composite rectangular segments, one wedged in another.

The materials used for the vanes changed from cardboard to metal foil and even spoons or plastic, as groups struggled to make what they had planned. While making, some groups found that the vanes tore when they attempted to pierce a hole near the vertex of triangular vanes. This led them to change the vane structure. Though the material of the vanes changed, all UE groups chose to maintain the number of vanes that they had first settled on (after discussions) all the way through to the making. This was not the case with the UM and RM groups whose vane designs were more tentative in shape, number and material. All groups in the RM setting had vanes made of foil but without a bend to facilitate the tapping of wind. It was only while testing their windmill models that they realised the need to bend the vanes. On the other hand, urban groups anticipated and discussed the assembly issues as well as the structure of vanes to harness the wind even at early design stages. A sample of completed windmill models from each of the three settings is shown in Fig. 5.

## Conclusions

Our study explored some of the design and cognition aspects that can be inferred from the design productions of students, who collaboratively engaged in the design and making of a windmill model. The D&T unit was structured to result in paper and pencil design productions in the form of exploratory sketches, technical drawings, list of materials, procedural maps and work distribution among group members. The unit was carried out in three socio-cultural settings: two in the urban schools (UE and UM) and one in a rural (tribal) school (RM). The cognitive aspects in students' productions were analysed in terms of several themes: use of graphical symbols, functional, spatial and analogical reasoning, materials and tools listed or depicted and evolution of design. The analysis yielded insights about the strategies used by students in the different socio-cultural settings.

Students effectively used exploratory sketches and analogies to conceptualise their design ideas. The vanes were the most explored components in all the three settings. In the exploratory stage, a few urban English groups selectively abstracted


**Fig. 5** Three windmill models from the three socio-cultural settings. Left column—UM groups; Middle column—UE groups; and Right column—RM groups

features of some components (e.g. tower poles) to focus on others (e.g. assembly). They even depicted labels referring to materials in their explorations. They communicated with members of their group not only through speech, but also using non-verbal modes of gestures and their drawings. Urban Marathi groups were more prolific than the others in their productions at this stage.

In their technical drawings, students used the conventions they were briefly exposed to for showing dimensions and units. The urban groups, more often than the rural ones, made use of conventions to show dimension with leaders, arrows and end lines in their technical drawings. The rural students depicted dimensions more in their procedural maps than they did in their technical drawings. The D&T unit allowed learning of new skills (of indicating dimensions) and knowledge (about materials), and provided opportunities to exercise and integrate the skills in practice. This was seen through students' continued use of conventions once learnt in all subsequent productions.

Qualitative thinking was seen through students' descriptions of materials (differentiating the thick from thin, flat sheet from rods, etc.). It was also seen in their attempts to relate the designed components to objects and materials known to them. These observations in the context of technological engagement among students point to the important role played by qualitative knowledge in the teaching and learning of technology (McCormick, 2004). The rural groups emphasised stability of the artefact, while the urban groups had greater variety in designs. Overall, the rural groups preferred to use materials that they were familiar with, like wood, hammer and nails, while the urban groups asked for glue of different types for joining a variety of materials. To indicate all this, the urban English medium groups more than the others used icons and symbols.

Students in all settings devised ways to represent their ideas in 2-D—indicating occlusion using dashed lines, using exploded and enlarged views and combining of multiple perspectives in the same drawing. Spatial conflicts in representing occluded objects or those in mutually perpendicular planes were resolved by resorting to X-ray drawings and multiple perspectives. This happened more often in the rural setting. Relative differences in the design productions in the three settings may have arisen from students' differential exposure to artefacts and drawings in the world around them.

The classroom observations and clippings in the video recordings revealed the dynamics of students interactions as they engaged in making their design explorations. Design productions in groups were made by students either sequentially or simultaneously. In a sequential mode, they negotiated their ideas after they had put them on paper. The ideas were further discussed and clarified either verbally or through the use of sketches and gestures. At times, students simultaneously made explorations on the same page and contributed to the group's emerging design. The nature of collaborative negotiation during design of the windmill structure and the dynamics involved in the course of design supports Anning's (1997) observation that in the workplace, exploratory sketching of ideas assists "collective cognition" in a team of workers. Assignment of tasks to group members showed interesting variation in the three settings. The rural groups assigned actions (cutting, joining) to members, while the urban groups assigned tasks according to components (making vanes, tower) and their assembly.

Design productions served to trace evolving designs. Students' designs were seen to have evolved in terms of the component shapes and sizes, assembly considerations and materials used. The preferences in the use of materials and tools reflect students differential knowledge and skills. The variety seen in the windmill model designs even within one setting indicates that a D&T unit of this nature can generate almost as many alternative designs as there are groups working.

## Implications

Design and technology does not exist in Indian school curricula. This report is part of a research study on development and trials of three D&T units. The study is the first to explore the parameters of a technology education curriculum at the middle school level in India. The design productions that emerged in the three socio-cultural settings in which the study was conducted points to the complex strategies that students (naïve designers) use. The study also indicates possible criteria that could be used to analyse students' design productions. Technology education in the country has so far been subsumed under science education as applications of scientific concepts learnt. The D&T units as structured for this study draw attention to technology as objects (artefacts), processes (of designing, making and evaluating) and systems (the windmill in this case). The unit emphasises both the design and making aspects of technological practice.

Using a *collaboration and communication centred model* (Choksi, Chunawala, & Natarajan, 2006) for the trials of D&T units, the research proposes a pedagogy that can encourage co-operation among students in Indian classrooms. Opportunities for collaboration in normal classrooms occur mostly as part of extra-curricular activities. The structure of D&T units offers opportunities for both individual and team productions, sharing of resources and negotiation of ideas. The nature of intra and inter-group collaborations and communications as part of students' activities in one of the D&T units has been studied and reported elsewhere (Mehrotra, Khunyakari, Natarajan, & Chunawala, 2006). The study seeks to make technology education applicable within the country's widely different socio-cultural settings. The wide variety of tasks even within one D&T unit can cater to students' varied interests, knowledge and skills and differential levels of exposure.

The model used for the D&T unit trials has scope for integration of a variety of school subjects in near-authentic situations: from concepts in science and mathematics to language use and articulation of values and judgements. In most school systems, drawings are either under-valued or at best used as depictions of finished products. According to Hope (2000), research in children's drawings has focussed on drawings as "finished product", rather than drawings for intent to make. Designing and making an artefact like a windmill model requires students to visualise and depict spatial relations between components and assemblies. It involves mental transformations, analogical and functional reasoning, and the use of conventions and notations. In the course of designing students make judgements about material properties, and estimate material shapes, sizes and quantities. Planned and controlled actions involved in making the artefact enhance manipulative and fine motor skills. Learnt and practised in an authentic setting as in the D&T unit, these skills can be valuable for the learning of school subjects (Benenson, 2001) like science (Gustafson, Rowell & Rose, 2000), mathematics (Bryant and Squire, 2001) and geography (Tversky, 2003).

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