3. DESIGNING DESIGN TASKS FOR INDIAN CLASSROOMS

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Introduction

Design involves iterative interaction of the mind and the hand (Kimbell, 1996). The designer is a reflective practitioner, interacting with the tools and resources of design (Schön, 1983). The growing research in the area of computer supported co-operative work (CSCW) has led to seeing design as a collaborative approach rather than as an individual activity. The role of cognitive processes like reasoning, creativity and thinking in the collaborative design activity has been mostly studied in specific domains like graphic design and architecture. In design situations, co-ordinated learning and work practices are seen to evolve through communication that is mediated and organised by artefacts (Perry and Sanderson, 1998).

Rogoff (1998), who has reviewed the research on collaborative learning and cognition, has emphasized the need for analysis of classroom activity on the personal, interpersonal and community or institutional planes to give a rich and complete understanding of the cognitive processes involved. Studies on classroom activities have shown that it helps student designers to gather a wide range of problem-related information (problem scoping) before they explore design alternatives while they are working on a problem, which has been set in their context (Atman, et al 2003).

Design involves visual thinking and the constructive use of mental imagery, which are of particular relevance in problem solving. The role of language in describing shapes, concepts and spatial arrangements is very significant and holds potential for linking thought to action (Solomon and Hall, 1996). Mental images may be shared without use of language, as in the case of exploratory sketches used by designers to share design ideas. The inherently incomplete nature of doodles and exploratory sketches makes them open for manipulations and spatial transformations with inputs from fellow designers (Richardson, 1983). These are a form of interactive imagery (Goldschmidt, 1994). They provide cues for retrieving new information and re-interpretation (Hope, 2000; Fleer, 2000) and assist 'collective cognition' (Anning, 1997).

Designers use models and codes that rely heavily on graphic images, like diagrams, sketches and technical drawing, to aid internal thinking as well as to share design ideas and making instructions (Cross, 1982). Technical drawings are part of the psychological tool set that mediate human learning (Vygotsky, 1982:137, cited in Cole and Wertsch, 1996). Anning (1997) and Nwoke (1993) advocate an exposure to technical drawings among students to serve several learning goals: to develop design and drafting concepts, creativity and spatially related problem-solving abilities.

D&T education as a part of general education

According to Cross (1982), design is a third culture, different from the culture of science and that of the humanities and the arts. He emphasized the need for integrating this design culture in the general education. Design has been included variously within D&T, technology or craft education as part of general education in different countries. The D&T education in the UK aimed at building technology capability, is based on the Assessment of Performance Unit (APU) project, includes features like the contexts, hierarchy and structuring the tasks, an extent of pupil autonomy, incorporating the iteration of action and reflection, collaboration allowing individual differences and maximising progression (Kimbell, 1996). Rowell (2004) advocates a technological stance in classrooms, which encourages capability building and still views technology activity as collective and social, situated in a community of learners in which knowledge is co-constructed. She emphasises the importance of both conceptual and procedural knowledge of and for technology (McCormick, 1997), which is gained through appropriate classroom practices.

The *US Technology Content Standards* and the included benchmarks prescribe the content knowledge and abilities that students should acquire to be technologically literate (ITEA, 2000). Design forms one of the five strands of the standards, and includes cognitive understanding of design process with an emphasis on the attributes of design, the engineering design process, and other problem solving approaches.

In India, neither design nor technology exists as a subject in the present school curricula. Except in the context of scientific diagrams and geometric constructions, devoting school time to drawings is seen as taking away from subjects like science and mathematics. Recent textbooks of the NCERT (apex national body for school education) portray technology as artefacts made by application of scientific laws and principles. Besides being an excessively narrow view of technology, it does not expose students to technologies that not only are manifest as products, processes and systems but as knowledge and activities as well. The technology-as-applied-science view de-emphasises design, as well as the skills, knowledge and values associated with technology as a human endeavour.

Though design has been considered a domain of activity for people across all cultures and all ages (Cross, 1982; Roberts, 1994), there is insufficient research on the nature and structure of design activities of school students (naïve designers) and their cognitive implications. In the Indian context rich in socio-cultural diversity, it would be relevant to study the nature of communication and collaboration within design-and-make activities and the role of socio-cultural factors. A study at HBCSE on design and technology (D&T) education for middle school students attempted to explore some research questions about design and the role of communication and collaboration as middle school students carried out D&T units.

Objectives of our study

This paper reports on the considerations that went into structuring three D&T units, the trials of which were conducted among middle school students in three socio-cultural settings. The research questions about design included the following: What kinds of design productions emerge when middle school students engage collaboratively in selected semi-structured design-and-make activities? What do students' design productions reveal about their design ideas and what insights do they offer about their cognitive activities? What role does the context, urban or rural, socio-economic and linguistic settings play in students' design productions and ideas?

The design productions of one of the units were analysed to understand the cognitive processes. Our findings reported here show students' cognitive activities as they engage in the design process, their use of technical drawings and their problem solving strategies (points of alignment with the US standards in design). The cognitive activities are discussed in terms of the graphicacy skills and the visuo-spatial reasoning. Analysis of their productions also reveals how the structure of the unit, the sequencing and nature of tasks, the structured communication and collaborative approach has influenced their design.

Methodology

Three prototypical D&T units were developed that could engage urban and rural Indian middle school students. The units were making a bag to carry a certain weight, making a model of working windmill to lift a given weight, and making puppets and collectively staging a puppet show.

The selection of a sample for the three D&T units included students from a range of socio-cultural settings and schools with different language of instruction. The themes for the D&T unit are diverse: the technological activities range from a product of daily use, a mechanical object to dynamic objects part of a larger system. Each unit included some tasks that required to be done collectively by the class while other tasks needed collaboration within smaller groups. The nature and sequence of tasks was designed to encourage collaboration and communication among students and researchers. This helped generate records of the design activity in the form of productions and explicit actions available for analysis. The language for instruction was the same as the medium of learning and instruction in schools. Each unit was carried out in every setting for over 15 hours spread over a span of 5 days. The units were presented in the same sequence, but at different times for the three settings.

Sample: The study included Indian middle school students, studying in Grade 6 (age 11 to 14 years), from three distinct socio-cultural settings: an urban Marathi medium school, an urban English medium school and a tribal (rural) Marathi medium school. These schools were selected to include diverse socio-cultural settings and the two different languages of instruction, namely English and Marathi, the language of the State. About 20 students from each of the schools volunteered to participate in the trials of the three D&T units. The sample distribution is given in Table1. An equal number of boys and girls were ensured. The D&T trials required students to form collaborative groups consisting of 3 to 4 individuals each. The groups were of three different kinds: two all-girls group, two all-boys groups and two mixed groups (consisting of equal number of boys and girls).

Table 1: Sample details

	Boys	***Girls***	***Total***	***Language of interaction***	***Location of trials***
English	10	09	19	English	HBCSE
Urban Marathi	09	13	22	Marathi	HBCSE
Tribal (rural)	12	12	24	Marathi	Tribal residential school

Designing the D&T units

The structure of the units and plan for classroom practice draws inspiration from the Assessment of Performance Unit (APU) project (Kimbell, 1996) and the technological stance for technology education suggested by Rowell (2004).

Each unit, set in a familiar context included a variety of tasks and sub-tasks that helped make it gender fair. There was scope for using a range of material resources, skills and concepts. The units were sequenced in increasing complexity of concepts and skills for middle school students (naïve designers) without any formal exposure to design activities. The structure of each unit afforded a mix of tasks, some to be done by individuals and some in groups. Specific criteria used for the design of three units of increasing complexity is summarised in Table 2. The units selected for the study are underlined in the table.

Table 2: Summary of criteria used in selecting three prototype D&T units

Criteria for design of the unit	***Prototype D&T units***
• Technology as product • Simple and familiar object of everyday use • A static object, single component or a simple assembly of a few components • Used by an individual • Knowledge of familiar materials • Simple skills of estimation, measurement, drawing, cutting, fastening	Design and make: <u>a bag</u>, a kite, a pencil box, a boomerang, a paper-plane
• Technology as process • Complex object, set in a familiar context • A dynamic object, a multi-component assemblage • Used by community/ group of people • Knowledge of materials and compatibility, knowledge of elementary mechanics • Complex skills of visualization, representation, tool handling, and assembly of components	Design and make: <u>a model of a windmill</u>, a cart, an airplane, a terrarium, a herbarium
• Technology as system • Set of objects as part of a familiar system • Dynamic objects within a system (static or mobile) • Used by group and community/ society • Knowledge of mechanics, materials, and sensitivity to aesthetics, socio-cultural settings and behaviour • Complex skills of visualization, representation, tool handling, and assembly of components, fine manipulation and co-ordination	Design and make: <u>puppets and stage a show</u>, a model of recreation park for people with special needs

This paper reports on students' productions in the unit on making a windmill model. Besides emphasizing the process facet of technology, this unit is complex involving an assembly of several components of which three, tower, axle and vanes, needed elaborate design. The working windmill model (different from the static bag) required students to incorporate several design considerations like the vane structure, smooth movement of vanes, mass distribution of the tower, etc., as well as aspects of construction and assembly. The unit required students to consider the internal (individual) constraints like the choice of appropriate materials as well as the external (system) constraints like height of the tower, weight of the axle and vane assembly, which would ensure the functioning of the windmill.

Trials of a D&T unit: model of a windmill

The unit on designing and making a windmill model, like the other two D&T units, was based on the collaboration and communication centred model. The trial of the unit was structured in terms of a sequence of tasks: Motivation and investigation, Exploration of design, Technical drawing, Planning to make, Making and Evaluating. (Choksi, et al, 2006) These tasks had fuzzy boundaries and overlaps. Exploration of design started students off on designing, which continued into the subsequent tasks. The structuring of these units for classroom practice was guided by cognitive issues and design aspects. The tasks and the design issues within each are discussed below.

Motivation and investigation: The first task was to set up the goal of the unit, negotiate constraints for the design and make activities to follow and engage students in a problem scoping (gathering information relevant to a problem) activity. All the students participated actively as the researcher narrated a story with scope for gathering students' ideas and descriptions of familiar contexts, like the objects and events in a fair in a city or village. The story led to a problem situation, for which making of a windmill model to lift a given weight was the solution.

Students, individually and in groups, gathered information about the structure and functional attributes of windmills using a variety of sources like books, magazines and newspapers. Groups of students were shown photographs and drawings of windmill models, computer animations and movie clips. They were primed to notice structural and functional aspects of the windmill that would help them formulate design better. A toy windmill (*firki*), which was part of the story narrative, was given to individual students. They handled it and each student drew it from a front and a lateral view (object drawing). This gave students opportunities to explore the structural and functional details of a familiar and related object, and they were requested to share their ideas with all others. Each group had to write a description or a poem on a windmill.

Exploration of design: While each group of students explored the design of their windmill model, they negotiated the ideas that emerged within the group through discussions as well as sketches, gestures and other non-verbal modes of expression. They began by engaging in discussions and making "doodles", the precursors of exploratory sketches. While in some groups, individuals made exploratory sketches, they had to negotiate with the other members to get it accepted even in a modified form. Other groups worked collectively, all members simultaneously sketching all over the page leaving very little graphical spaces[1]. The evolution of the sketches, especially in such "team sketches", showed evidence of "collective cognition" (Anning, 1997). Exploration of design started students off on designing and students redesigned or modified their original designs right up to the making and evaluation tasks.

[1] Graphical space is the space between graphic elements, analogous to the space between two words in text (Tversky, 2002)

Technical drawing: A technical drawing allowed abstraction of relevant features using appropriate conventions to depict dimensions and details, without the effort involved in shading and drawing perspectives. Students were given an exposure by way of a formal hour-long session on the use of conventions of depicting dimensions of object parts and units, of measurement using dashed and dotted lines, leaders and arrows. It was presented to them as a language that helped designers, engineers and architects to depict details of an object, overcoming the limitations of verbal language. The session included depiction of objects of various materials and shapes. Each group had to make a drawing of their conceived windmill model design using the conventions of technical drawing.

The technical drawing, one by each group, was made by a student, who the group believed was good at drawing. Other members in such groups advised on the aspects to be included in the drawing. Groups used rulers and other instruments in the school geometry box to make their depictions neat. The choice of perspective in the technical drawing was left to the students. Groups had to give a list of materials required for making their windmill model. Students knew that these resources would be provided to each group for the making task. Each group indicated the material of each part and the quantity of material required to make it either as labels on the drawing, as a separate list or in the form of a table. Some groups even included tools in their list.

Planning to make: Each group had to provide a step-by-step procedure (procedural map) for making their windmill model. An exemplar procedural map, for making a toy windmill or a decorative lantern, showing the description of steps with corresponding illustrations, was displayed in the class. The students could study it.
Members of each group helped each other in visualising and organising the anticipated actions and produced the procedural map for their group's windmill. In most groups, one of the group members drew the illustrations for each step and another wrote the corresponding descriptions, at the same time. Other members of the group supervised and gave suggestions. Each group had to assign sub-tasks to each member. They sometimes assigned based on skills typically associated with the individuals (carpentry work to some and cardboard or metal sheet cutting to others) and at other times they made random assignment.
Each group of students presented its design (technical drawing) and plan of making including materials and task distribution to all the groups. The feedback was used to modify design, materials or procedure depending on the suggestions made.
Making: Most groups worked as "teams" towards construction of their windmill models, as all members collaborated in achieving their common goal. The members willingly took up responsibilities, helped each other in activities like cutting, boring, etc., besides the sub-task they had been assigned. During the making, groups took decisions about the workability of their vane structure, the mobility of the vanes and the strength of the tower. After making their windmill model, they tested its working using an experimental set-up. They tabulated the conditions under which it worked and its maximum efficiency in terms of a few relevant parameters like distance from a constant speed wind source, the maximum weight it can lift and the rate at which it can lift. Ensuring that their windmill models worked involved the groups in redesigning at all stages of making.

Evaluating: The product, which was a windmill model that worked when there was wind and could lift a given weight, was evaluated. The groups used an experimental set-up, consisting of a blower set at constant wind speed and a stool with angle markings, to test the working of their model. Some of the models failed to work or broke down. These groups redesigned their models, sometimes with helpful suggestions from other groups, and made the models work.

A sheet with a list of possible criteria including the table for noting test data as well as properties like dimensions, sturdiness, aesthetics, etc. were provided to the students. Each group evaluated their own model and those of other groups using the given criteria. This provided students an opportunity to appraise designs and realise the merits and demerits of design alternatives used to address the problem.

Students were asked to present the product evaluation to the class. They talked of their product properties, stated its weaknesses, the problems they had encountered while making and how they had solved them. In addition, they gave suggestions for improving the quality of other groups' products.

The communication and collaboration centred model of D&T units provided students several opportunities to express, negotiate and critique the designs and products of their peers. Individuals negotiated the design within their group and groups defended their design and product to other groups, while critically examining others' designs and products. Unlike what has been reported in a few studies in D&T education, where students found it difficult to talk about technological activity (Fleer, 2000), the D&T units in our study were "designed" to encourage communication, whether initiated by the researchers (structured) or spontaneous ones within and outside groups (unstructured). The diversity in tasks and productions, like writing and reciting poems and descriptions, doodling, sketching, designing and making a product, elicited a variety of modes of expression and generated a variety of data. Among the data were the design productions: sketches generated during the exploration of design, technical drawings and procedural maps.

Analysis

The design productions in the D&T unit on designing and making a windmill model to carry a given weight, which were made by the total of 19 groups from three socio-cultural settings, were either elicited by instructions or spontaneously generated. Based on Schon's (1983) reflective practice theoretical framework, Barkman (2001) characterised the design process among expert designers by four kinds of activities: naming, framing, moving and reflecting. These ideas gave us useful insights in looking at the design process among groups of students who are naïve designers.

Students, working in groups, first <u>named</u> or identified the main issues in the problem and made a choice for what they thought mattered in the design situation. In their exploratory sketches, most groups of students focused on the vane or tower structure.

Students attempted to <u>frame</u> the problem in terms of some of its parameters, like the materials they can use for the vane and tower structures, or the function of the windmill and the feasibility of a component serving this function. Even as groups of students explored their design they seemed to weigh the consequences of their design decisions and <u>move</u> from one alternative to another. This was seen from several alternate vane structures in the design explorations along with sketches of assembly and even lines indicating motion.

The design productions gave evidence of students evaluating their moves and frames. This led to construction of another move or reframing the design situation. In the productions of one group, the vane structure, in the form of a composite “cross” was arrived at after much framing and moving activities, that is after reflection. They had considered, as seen from their sketches and labels, the assembly of two flat segments of wood, the tools, and the process to be employed for making it.

Design productions are a window to the cognitive activity involved in the design practices of naïve designers. The use of visuo-spatial skills in thinking and reasoning are reflected in designers’ diagrams, a key to effective collaborative problem-solving (Heiser, Tversky, and Silverman, 2004). In the study reported here, groups of students interacted with each other, and negotiated ideas. While doing so they constructed mental representations, which were externalised in the form of design productions. Their representations and the externalised design productions were mirrors of their thoughts and served as constructive aids in the design process. The productions placed limits on the transformations of objects they were depicting, as students selected and structured the information available to them (Tversky, 2002).

The different kinds of productions served different purposes of design. The productions as well as the design got progressively refined. Analysis of these productions gave insights into some of the cognitive activities in students’ design engagement.

Evidences of cognitive activity in students’ design productions

Students generated three kinds of design productions: exploratory sketches, technical drawings and procedural maps. These productions were analyzed for students’ cognitive activities indicated in them. Students’ designs are characterised here in terms of graphicacy skills and evidences of visuo-spatial reasoning as listed in Table 3. The differences in the design characteristics of students’ productions from different settings are also discussed under the corresponding design features.

Table 3: Design characteristics and features in the productions that indicate them

Design characteristics	***Indicative design features***
Graphicacy in design productions	• use of symbols and icons • from 3-D (3 dimensions) to 2-D and perspective choice
Visuo-spatial reasoning	• analogical reasoning • symmetry, tessellation and repetitions • evolution of design ideas • making and redesigning

Graphicacy in design productions

Graphicacy is the ability to understand and present information in the form of sketches, diagrams, plans, charts, and other non-textual, two-dimensional formats. The information conveyed may be representative of what we see (object drawings) or more abstract. Abstract information may be spatial (maps, plans and technical drawings) or numerical (tables, graphs)

(Aldrich and Shepard, 2000). In the design productions, students from all settings, no matter how detailed or brief in their depictions, displayed skills of graphicacy to varying degrees; of making sketches, drawing diagrams using annotating and labelling conventions, and choice of perspective.

The urban groups were more prolific in making exploratory sketches than the tribal groups, who had a tendency to erase and redraw on the same paper, even though they were instructed to retain all their rough work. Their tendency to be conservative in the use of resources limited our access to records of their design ideas.

The procedural maps for the windmill designs varied in content and level of details for the urban and tribal school students. In general, the urban groups had neater illustrations and brief descriptions of each step in making. Tribal groups had detailed descriptions for each step and included dimensional aspects in the description rather than in the illustrations. The tribal and urban Marathi students were very methodical in terms of the general layout. They demarcated the margins, drew boxes, made illustrations and wrote descriptions within it.

Use of symbols and icons: Naïve designers in this study invented graphical symbols, like hazy lines, circles and over tracing, to depict components or motion. It is interesting that different student groups used similar symbols. However, a symbol like a curved line was used in different contexts, by the same group, with different meanings: motion, tentativeness in a component structure, or isolation of exploratory sketches one from another. An urban Marathi group used circular lines around the vane assembly to suggest motion and at the foot of the tower to represent a disc or base-like structure. Some English groups used hazy and discontinuous lines to suggest tentative poles and vanes. Such selective and specific use of graphical symbols has been reported in professional designer's sketches in studies on design and visual thinking processes (Cross, 1984; Do & Gross; 2001).

Students' productions from the different settings varied in levels of detailing and use of conventions. The English groups and urban Marathi groups had annotations in their technical drawings, which depicted dimensions and units, leaders and arrows and neat labels. Fewer tribal groups had annotations in their technical drawings, while most groups had problems using the technical conventions of leaders and arrows. In their procedural maps, the English groups used referent labels, showed icons of tools (hammer, scissors) and making actions. Some of the tribal and urban Marathi groups included "measuring and marking" as a significant step in planning and making in both drawings and descriptions. A tribal group depicted a measuring device (ruler) with detailed markings alongside a wooden piece to show its length, but did not align the zero of the ruler with the end of the piece.

From 3-D (3 dimensions) to 2-D and perspective choice: Students chose to draw in their technical drawings a lateral perspective that could be used to depict more details of the assembly over a frontal one that would occlude most parts. Students resorted to spatial reasoning in resolving problems of diagrammatic representation of 3-dimensional objects. They used multiple perspectives to show different components in the same drawing: several groups showed all the vanes (a perspective between frontal and lateral) in their technical drawing in which the rest of the components were shown in the lateral view. When a group ran into a difficulty depicting a composite vane of two flat, mutually perpendicular segments, they resolved it by depicting it as a flag-like structure from a frontal perspective.

Most urban groups, and two tribal groups found ways of indicating depth in their drawing using imaginary base lines and size differences between the object parts in front and back: a tower shown with two longer, thicker, front poles and two shorter, thinner back poles. More tribal than urban groups' productions had x-ray drawings, though it is reported that students above nine years of age do not normally make x-ray drawings (Anning, 1997). However, some tribal groups did use selective occlusion and dashed lines for occluded parts in their depictions. The presence of x-ray drawings, and more in our tribal sample, may indicate a lack of exposure in some settings to graphics in the formal design context.

Visuo-spatial reasoning

In the context of collaborative design, drawings make public the private thoughts of individuals so that they become available for collective use and revision within and outside groups. The design productions inform us; through the shifts in design ideas and resources used and are a window to the thought in the design and plan of an artifact.

Evidences for visuo-spatial reasoning were seen at several points in students design. This could be more readily seen when illustrations depicting spatial arrangements were accompanied by verbal descriptions, as in students' procedural maps. Producing technical drawings and procedural maps involve another important aspect of visuo-spatial reasoning in the design context, namely, functional reasoning: dimensioning the components and their parts, matching the dimensions to their relative sizes and functions. Problems in students' functional reasoning were indicated by the mismatch between the specified lengths of different segments of a vane and its total dimension. An urban Marathi group showed the three segments of a strip in a (two-strip) cross as 5 cm each, while the total strip length was shown as 10 cm.

Students used their language skills to communicate their design ideas to their peers and as they tried to be clearer and unambiguous, they developed the language of design and technology. They often used the non-relative orientations "vertical" and "horizontal", described shapes of components as "cylinder shaped" and referred to relative proportions like "equal parts" or "a hole the size of a nail".

Students used the technique of *selective abstraction*, a term used for reducing some components in a complex assembly to icons in order to facilitate elaboration of other aspects of the assembly. Some urban groups represented the vanes as sticks while conceiving the complex assembly of vanes, tower poles and the axle. Such evidences suggest students' mental operations that facilitate thinking, reasoning and enable effective communication of information in collaborative student groups. Collaborative completion of design production was typically observed in urban groups. A sentence started by one student was completed by another, a description by one student was depicted as an illustration by another and an illustration by one student was modified by another.

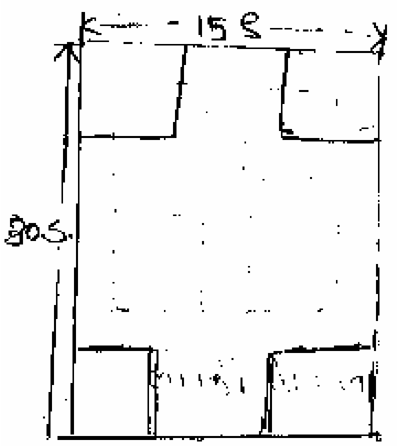
Analogical reasoning: The use of analogies by some groups in all three settings was indicated in their exploratory sketches. This was corroborated by video records of discussions among group members, use of select objects around them and non-verbal communication. An English group used a five-pointed "star" to represent the vane structure in their design exploration. A tribal group used the analogue of the size of a thick nail to describe the size of a hole in the wooden block in their procedural map. Students used objects around them to explain the envisaged structures during negotiations within groups. An urban Marathi group used two rulers positioned in a cross to indicate the arrangement of their vanes, while another group used a ruler to represent its tower and showed the position of a hole for the axle. Novel objects in their surroundings such as a tripod camera stand (brought by the researchers for video recordings) inspired the tower design of a couple of groups.

Symmetry, tessellation and repetitions: All groups of students designed symmetric vane structures. Most groups had even number of vanes from the beginning of design exploration. It was interesting that those who started with an odd number of vanes soon moved to an even number. The vane and tower structures involved making and assembly of several identical parts. Students had to cut out these identical parts from sheets of material, say wood, foil, etc. Only a few groups tessellated the shape of the part on the sheet to economise on material use (see Figure 1). All others planned to cut each shape in isolation: like all triangular shapes arranged with bases along the same edge of the sheet. Recognising the tessellation possibility while making the procedural map required mental rotation and reorientation of imaginary objects and the motivation would come from sensitivity to economic use of resources.

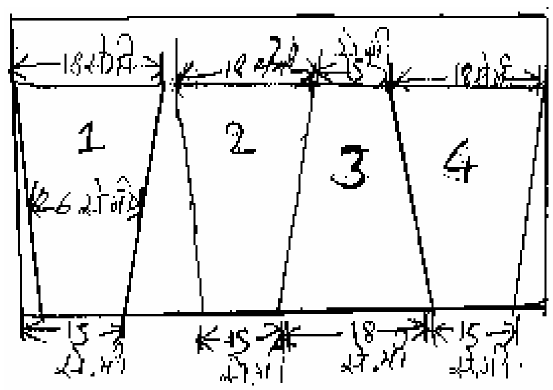
Though all groups used symmetry in their design, they did not us it to advantage in the plan for making or while cutting materials to shape. They depicted the identical shapes as many times as they occurred in their component: the vane was drawn four times to show that four vanes had to be made before assembly. Most groups did not recognise that a single vane with an annotation for making four pieces could have served the purpose.

Figure 1: Economy of resource use achieved by tessellation

(a) Markings on a wooden block for four poles of the tower



(b) Partial tessellation of wooden pieces for the four sides of a tower



Evolution of design ideas in design productions: 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. 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.

Making and redesigning: Students had, from exploring design, through technical drawings to producing the procedural maps, anticipated the making actions. They had considered how they would assemble the components, the tools they would use and how they would make the vanes move smoothly or the tower stable. Their ideas were refined by inputs from their peers during communication of their designs.

Diversity in designs was observed more among the English groups than in the other settings. The urban groups designed using a range of materials for different components of their windmills: styrofoam, wooden ice-cream sticks, metal foils, tin containers, wood and plastic. The tribal groups, on the other hand largely used wood, cardboard and metal foils. This difference in variety was reflected in the choice of materials for joining components and their parts: the English groups preferred glue, packaged (branded) adhesives and sealants. The urban Marathi preferred hammer and nails and sometimes, packaged adhesives. Tribal groups mostly relied on hammer, nails, wires and a packaged adhesive familiar to them.

Issues of strength, durability and how their model would work surfaced in the design productions of all groups. They described their material requirements with properties and referred to its effect on their model: thick wood for a sturdy tower, thin wire for assembly, etc. Issues of stability and rigidity of the windmill models emerged less often among the English groups.

Members of each group negotiated design changes, shared ideas as they collaborated towards the realisation of their windmill model. Most of the groups made minor modifications while one group changed their design radically. Students used their own criteria for deciding on the suitability of each component during the making task. For instance, some groups placed the axle and vane assembly in front of the fan to test its movement. They modified a component or assembly when they found it unsuitable. The design changes were also initiated by obstacles in construction and assembly of components and by realisation of the availability of alternate resources. Thus, though exploration of design started the design process, for students it was an ongoing process that permeated all subsequent tasks.

Conclusions

Design and technology has not been a part of school education in India. A project at HBCSE studies the issues involved in introducing D&T as a school subject. As a part of the project, three prototypical D&T units centred on collaboration and communication were developed for middle school students (naïve designers). This paper focused on two aspects: (i) the key features that were considered in the development of three D&T units, their design and classroom trials, exemplified by the unit on windmill model, and (ii) the reflections of students' cognitive activity in their design productions while designing and making a windmill model. The structure of the design unit where students worked in groups within a collaborative learning environment helped make it gender fair engaging for students from all socio-cultural settings.

The trials resulted in three qualitatively different kinds of design productions that were analysed in terms of graphicacy skills and visuo-spatial reasoning – exploratory sketches, technical drawings and procedural maps. The design productions of students from all settings were rich in graphical symbols and icons. They invented and used them to depict components or motion in their sketches, which some groups produced collectively, completing each others' ideas. Collaboration within groups was a key feature in all the settings and was reflected in the productions as well, sometimes through sharing of ideas and collective cognition.

Students showed dimensions that they had been exposed to, and displayed a repertoire of strategies for depicting their ideas. They tackled the difficulty of translating from 3-dimensional objects and their images to 2-D depictions through a variety of ways. They used exploded views, chose suitable perspectives (views), multiple perspectives in the same sketch or drawing, dashed lines, and occlusion. Some used x-ray diagrams as well. Students produced sketches where they selectively abstracted features to be able to focus on relevant aspects of design. The productions from the different settings varied in levels of detailing and use of conventions.

Students spontaneously used analogies to initiate and develop their design ideas, some of which came from objects around them. Symmetry in components was the hall mark of the designs in all settings, reflected in the shape and number of vanes and shape of tower. However, they did not use this to achieve parsimony of depictions through tessellation or for economy of resource use while cutting up sheet material for making. Design in all groups evolved in two major ways: in terms of shifts in shapes and assembly of components and shifts in material choices. The students used over dozen different materials in the design and making of the windmills. There were almost as many different assemblies with a variety in the materials, shapes and sizes of components as the number of groups. Diversity in designs ideas and materials was more among the English groups than in the other settings, where issues of stability and rigidity emerged more often.

The process of design was motivated by the initial story or context and investigation. Design, was explored collectively by members of each group, who negotiated the various parameters of their design to arrive at their technical drawings. They reconsidered their designs as they planned for making, and redesigned components and assemblies while making and after testing. Thus, design permeated through all tasks in the D&T unit structured to engage students in designing and making a windmill model for lifting a given weight.

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