THINKING THROUGH DESIGN: TEACHERS EXPLORE A DESIGN AND MAKE TASK

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The paper reports an initiative to introduce design and technology (D&T) education to Indian middle school teachers. A one-day workshop with teachers, which engaged them in a design and make experience, also allowed participant teachers to share their ideas and views about the relevance and potentials of including such activities as part of school curricula. Analysis of teacher engagements and their feedback on activities provided insights into what teachers perceived as design activities, what would be relevant for students in the school context, the potential hurdles and enablers for including D&T education in schools. Besides, the study also reveals the cognitive and affective aspects of teachers immersed in design and make activities, thus making a case for the rich benefits of D&T activities.

Keywords: Design and technology education, Designing, Making, Teachers' ideas

INTRODUCTION

Design and technology is not a school subject in India, where mathematics and science learning are emphasized, with explicit focus on activities. Yet, teachers and schools find it difficult to include hands-on activities to teach a subject. Activities, especially those set in authentic contexts, involve concepts and procedures learned in different subjects. Teachers neither see the relevance of making connections across school subjects nor have the means to help students do so. Hence, even when activities are conducted by teachers, learning opportunities are lost. Designing and making activities provide the rich contexts within which the participants spontaneously use concepts and knowledge (Khunyakari, Chunawala & Natarajan, 2007).

Design and technology activities

Design, used both as a noun and a verb, represents the product and the process. Technology, on the other hand, may manifest as object, activity, knowledge and volition or human desires and intentions (Mitcham, 1994). Design, the core of any technological endeavour, involves visual thinking, constructive use of mental imagery and purposeful manipulation of available resources. The design brief presents an ill-defined problem, which gets elaborated through the investigation, critical analysis and exploration of solutions. Hence design activity is problem focused, that is, the activity seeks to understand the problem. In contrast, most problems in school science and mathematics are solution focused, as the problems are well defined.

In D&T activities, the differential availability of materials, resources and tools, and knowledge of operating constraints, lead to variation in problem definition as well as variety in potential solutions. The process of actualising (making) the conceptualized design involves critical judgements and decision-making. The outcome of design – a product, process or a system – should address the intended purpose outlined in the design brief. D&T includes evaluation and improvements of the outcome. Hence, in principle, it is an iterative process.

D&T activities and educational goals

D&T activities, when introduced in the curriculum, serve general educational goals as well as learning objectives associated with specific tasks. Importantly, D&T activities involve co-ordination of the mental and the manual towards generating a desired outcome. The theory-practice or the *episteme-techne* hierarchy dissolves in a D&T engagement set in an authentic context, which also calls for integration of knowledge, skills and values from different domains of art and craft, natural sciences, social sciences, mathematics, etc.

Engaging in design activities builds values of practicality, ingenuity, empathy and a concern for appropriateness (Cross, 2002). The engagement offers several cognitive benefits encouraging individuals to visualise, manipulate in their mind's eye and use the language of design - codes and symbols, sketches and models – to externalise their ideas. Besides, individuals working in groups develop soft-skills of collaboration and team-work.

Context for the study

Several of the educational benefits discussed above are supposed to derive from existing school subjects. For instance, art and craft are intended to offer students opportunities to engage with materials and ideas. In practice, these subjects are not considered critical for students to be promoted to the next level, and are taught in a prescriptive way, encouraging reproduction of templates. Research studies at Homi Bhabha Centre for Science Education (HBCSE) have cited the potential benefits of introducing D&T education in schools (Ara, Natarajan, & Chunawala, 2009; Choksi, Chunawala, & Natarajan, 2006; Mehrotra & Khunyakari, 2007). However, designing is a complex process which needs to be understood by teachers if they are to enable their pupils benefit from design activities (Fasciato, 2002). The varied experiences of teachers presented by de Vries (2007) shows that a teacher's perception of D&T activities can influence the structuring of students' experiences and "good educational strategies can do a lot to compensate for poor (*classroom*) conditions" (p. 5). Hence teachers themselves need to experience and reflect on the different aspects of D&T activities so that they become aware of its teaching and learning possibilities and challenges. The study reported here on a one-day workshop with teachers of diverse subjects from different schools is an exploratory step in that direction. Analysis of teachers' engagement allows us to probe the strategies that teachers use in designing, the connections they make between the activities and their perceived ideas of students' learning goals.

Research Objective

The study reported in this paper addressed the following objectives:

- To study the strategies used by teacher groups in designing and model making
- To study teachers' ideas about what it means to engage in designing and making and its potential learning benefits for students

Methodology

A one-day workshop, titled *Thinking through Design* was conceptualized for middle school teachers of different subjects, who were invited from about a dozen schools in Mumbai. The workshop began with a short introduction to D&T education, followed by design and make tasks that teachers engaged in. The activities and worksheets were structured to elicit teachers' ideas about design activity and their perception of its links with school subjects. The workshop also hoped to initiate a network of teachers and researchers that can collaborate in sustained educational development in general and school level D&T education units in particular. Besides, the network can motivate teachers to address several issues in education.

Sample

The sample consisted of 22 teachers (18 female, 4 male) from 10 English medium schools in Mumbai, which followed CBSE board or Maharashtra State Board curricula. Five of the schools were run by the Atomic Energy Establishment, and 5 were privately funded schools. None of the teachers seem to have had any exposure to D&T education.

Structure of the workshop

Beginning with an introduction of the research group and its activities, the potential benefits of engaging students in D&T activities were presented. The participants were divided into 6 groups of 3 to 4 teachers each, and each group had to name itself. A design brief was given:

> *You need a multi-purpose activity space to conduct a range of activities for your students (school). Suppose you are given a land of 100 sq m to build on. Design the space and structure for carrying out the teaching learning activities you want to include. Make a model and share your ideas of a workable/ practical design with others.*

Each group had to collaboratively sketch on the sheets provided, and then translate their idea into a 3D model. Material resources for constructing models were made available: chart-paper of different colours, straws, cardboard sheets, boxes, colour pens, cello tape, stapler and pins, rubber bands, ice-cream sticks, adhesive, cutting tools, etc. Each group had to share its ideas and experience of designing and making with all participants.

Data

All the paper pencil productions generated by each group was preserved as group portfolio. The actual models were preserved and photographed. The activities, including the formal presentations, were audio-visual recorded. Teachers' written responses were obtained on a few questionnaires after they had engaged in the design and make activities: (a) learning links questionnaire, (b) describe a design activity, and (c) feedback form.

Analysis Framework

The productions and responses have been analysed for insights into teachers' perceptions of designing and making experiences. The analysis concerned teachers' reflections of purposes and scope of design activities, and the cognitive aspects of teachers' design engagements.

- Teachers' subject interests were noted from the *'self information sheet'* filled by them.
- The *learning links questionnaire* filled by each teacher asked (a) for the learning objectives and general goals of education that the activity may serve; (b) whether they perceived a need to modify the design and make activity to suit their students, and in what ways; (c) if they had

conducted a similar activity among their students, and if so the details of the activity and its outcome; and (d) to describe a design activity (different from the day's activity) that they can carry out with their students and link it to learning objectives. Teachers' responses on each aspect was noted and analysed.

- Design thinking patterns were analysed from the design sketches, annotations, final drawings and products.
- The findings have been organised and discussed below under two main heads: teachers' responses to questionnaires (first 2 items) and design productions and models made by groups (last item). The *'feedback sheet'* gave insights into teachers' reflections on the workshop.

Analysis of Responses to Questionnaires

The participating teachers taught different subjects; most taught more than one subject. Half the participants (11) were teachers of science, followed by mathematics (9), English and social studies (6). Four teachers taught Craft and/or Art. There was only one teacher each of environmental studies and Marathi (State Language). The diversity of teachers reflected in the variety in responses to the questionnaires. These are discussed below under the heads of (a) educational goals and learning objectives (learning links), (b) suggestions for modifying the activity and (c) ideas for a design activity.

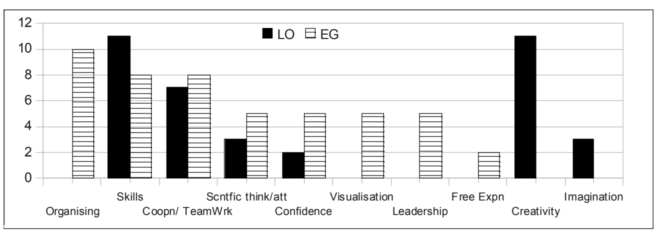

Figure 1: Teachers' ideas of educational goals (EG) and learning objectives (LO) of design activities

Educational goals (EG) and learning objectives (LO): When asked to suggest the possible LO of design activities and the general EG that these may serve, most teachers gave similar responses to both the questions (Figure 1). EG (8) had greater variety than LO (6). Half the participants felt that design activities done in groups could help students develop *organising skills* (EG). *Leadership* qualities, *visualization* and *freedom of expression* were mentioned as EG. The aspects given both as EG and LO included development of *skills* like reasoning, drawing and problem solving, *cooperation*, *scientific attitude or thinking*, and *self confidence*. The largest number of teachers referred to *creativity* (11) as an LO of design activities, while a few mentioned *imagination*. This reflective exercise highlighted that teachers linked general goals to design activities, but were unable to link it to subject specific learning objectives.

Modifying the given design activity: More than half the teachers (14) wanted to modify the given activity before conducting it with their students. They suggested adding material constraints, exposing students to architectural structures and building materials, and allowing students to modify the activity. Several aspects were appreciated by the teachers: practical aspects of the workshop, and emphasis on hands-on and minds-on experience were mentioned by most teachers. They also liked the focus on designing, teamwork, opportunity for interaction (6 teachers) and creativity (5 teachers). Discussions, knowledge, experience, model making and planning were other aspects that teachers gained from the workshop.

Teachers' ideas of design activities: Half the teachers (13) had earlier experiences of similar activities. Four teachers had facilitated science projects, while three mentioned conducting activities in Art/ Craft classes, and two each in EVS, mathematics and social science. Teachers' earlier activities were science or craft activities. However, their suggestions for a design and make activity show a trend towards a "designerly" understanding.

When asked to describe a design activity that they could carry out with their students, teachers included "designing waste disposal system in the school", "making eco friendly math-science models", "designing a lamp which gives more reflections, saving energy", "staging Egyptian/ Chinese play using puppets", "constructing a biogas plant", and organising for an "eco-club". In comparison to the activities they had earlier carried out with their students, the context of this question showed teachers' developing conception of design activities.

As found in the responses to questions on educational goals (EG) and learning objectives (LO), in the question on design activity too teachers did not mention subject specific learning objectives. Depending on the activity, the suggested LO included environmental awareness, learning about energy conservation and renewable sources of energy, team work, ability to work together for a common cause, developing a sense of social responsibility, developing motor skills, script writing, and puppet making.

Analysis of Design Productions and Models

The design brief that specified only the general purpose and the area allotted (100 sq m) allowed freedom of shape, materials, structural and architectural details. For instance, teachers were free to choose the number of levels and rooms, the nature of partitioning walls, etc. They were exposed to a range of possible considerations for structures and were shown pictures of a few examples.

Teachers worked in groups to produce design sketches and then made models. Representing ideas on paper is a cognitively demanding task. According to Tversky and Suwa (2009), drawings require a "a degree of coherence, completeness, and consistency" and are also used to test design ideas. Sketching requires less time than making models and it is easier to make sketches and make changes in them. Models, on the other hand, give a clearer idea than a sketch of the objects and spaces. Both are important in design.

The sketches and models were analysed for evidences of quantitative reasoning, estimations and calculations. Salient features of the different group designs are summarised in Table 1. Representational strategies were noted for consideration of the third dimension of height of the structure. Variety in designs was analysed in terms of elements (like windows, doors) and partitions as well as materials used. Aspects considered like environmental sustainability, climate, number of students, nature of activities were often seen in the annotations and models. Resemblance of models to sketches, focus on aesthetic aspects and collaborative teamwork were also noted. Each group's design as seen from the sketches and model was different from the rest. As shown in Figure 2, the structures occupied plots of different shapes.

Figure No.	Name of Group	Shape of plot	Plot area, sq m	No. of levels	3D sketch
2a	Budding Designers	Hexagon	93.4	1	Yes
2b	Creations	L-shape	100	2	No
2c	Cocoon	Square	100	3	Yes
2d	The Beavers	U-shaped	Not calculated	3	No
2e	Homi Bhabha	Square on stilts	81	2	No
2f	Activators	Circular	95	2	Yes

Table 1: Salient features of the activity space designed by different teacher groups

Quantitative reasoning in sketches: Teachers had to decide about shape and dimensions through quantitative reasoning using formulae connecting area to lengths. All groups except one decided the shape of plot their structure would occupy and then attempted to calculate the dimensions. The calculations were usually done by one or two members in the group. One group initiated sketching without attempting any calculations.

In most sketches, the numbers indicating dimensions were written along a line like labels, which had neither units nor indication of limits of dimensions. This is possibly because the teachers, including the 4 art/craft teachers, were unfamiliar with conventions for indicating dimensions in drawings. One group used *sq m* instead of *m* to indicate length (Figure 2c). An L-shaped sketch (Figure 2b) showed lengths without units, and the drawing was not to scale or proportion: two lines of 5 units each were drawn in unequal lengths. In another sketch they used units of *cm*. Several groups ignored scale or proportions of lengths even in their final sketches. Secondary school teachers, it appeared, found quantitative and technical representations a challenge, possibly because art and craft are under-rated subjects in school.

Calculating lengths from area: In most cases the area of the plot used did not equal 100 sq m. Three groups which used formulae to calculate the dimensions, ended up with less than 100 sq m plot area (Figures 2e, 2a and 2f). Teachers possibly preferred to work with whole number lengths. By trial and error they chose the nearest whole number lengths that gave areas less than or equal to the given area. One group (Figure 2f) approximated the radius to 5.5 m. In the case of square-on-stilts structure, lengths shown in the sketches were different from those used in area calculations (Figure 2e). Leaving 1 metre on all sides of a 10 m x 10 m plot, they wrongly assumed sides of 9 m and calculated an area of 81 sq m.

One of the groups did not attempt to translate area into lengths. Their U shaped structure (Figure 2d) had two parallel rectangular areas each marked 21 sq m with a connecting rectangle at one end of 25 sq m. The middle area was not provided. Besides, the relative areas marked in the sketch are not in proportion. Interestingly, none of their 3 exploratory and 2 final sketches indicate any length dimension. Overall, it appears that all groups had problems in deriving length specifications of their plots from the given area. Numerical literacy is an important aspect of schooling. It appears that design and make activities can provide opportunities for quantitative reasoning in authentic and meaningful contexts.

The third dimension: Most sketches show a plan view. Three groups attempted to sketch the third dimension (height) of their structure (hexagon, Figures 2c and 2f). These depictions are combinations of cut-out, elevation and cross-sectional views to indicate details that could not be depicted in the plan view. Only one group (Figure 2f) labeled height as 27 "feet". Others merely labeled elements, like the level (ground, first), staircase, rooms, etc.

Manipulating the third dimension: Designing 'a multipurpose activity space' suggested a 3-D structure, of which the plot area was specified. The teachers used the liberty in height to maximise space utilisation. Teachers' efforts to efficiently manage space may be related to the acute space crunch they experience in the mega-city. Five of the groups designed multi-level models, two of which had 3 levels. However, three groups had open un-partitioned terrace levels (Figures 2b, 2d and 2e). It was noted that groups that had complex structures, as dynamic partitions or multiple levels

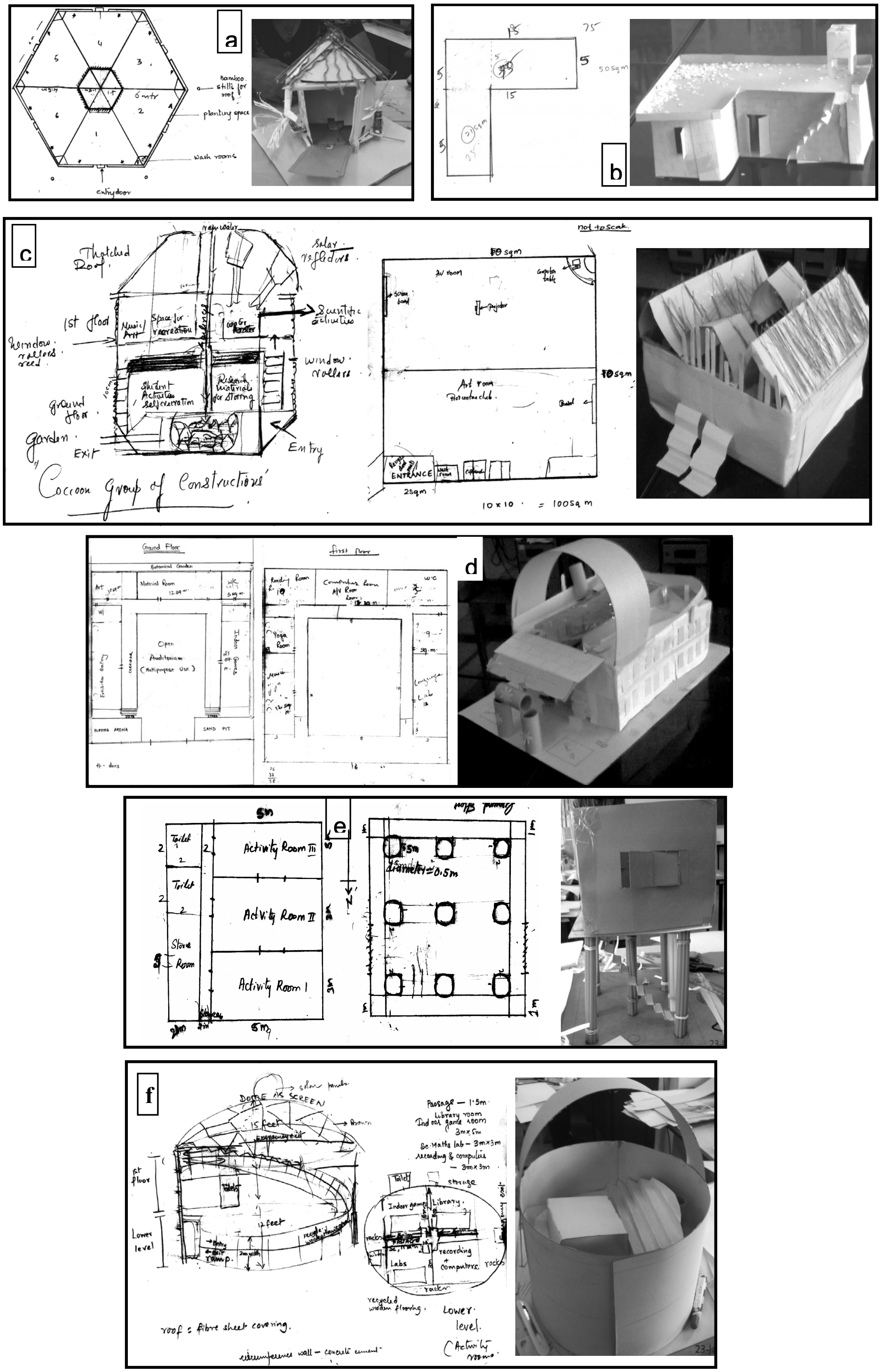

Figure 2: Representative sketches and models showing variety in designs

with a variety of activity spaces, resorted to sketching the third dimension as mentioned earlier.

Partitioning and structural elements in sketches and model: Most groups used static or permanent partitions like walls for creating rooms and spaces for simultaneously conducting multiple activities. One group (Figure 2a), however, designed dynamic partitions that could be put in place at will. Doors and windows are normally considered as essential elements of any human habitat. Yet, most sketches indicated one door and hardly any windows. One group (Figure 2b) had neither windows nor doors in their sketches. This may have been a limitation of their sketches of plan views, in which they were unaware of the conventions to indicate doors and windows. However, the models of all groups included at least one door and several windows; one group (Figure 2d) had 44 windows. Some merely drew windows on their model. Some groups detailed their designs of ramps, staircases, stages, and wash rooms. Teachers, like students (Khunyakari et. al., 2007), devised their own strategies to visualize and represent details of their designs both in sketches and as models.

Additional design considerations: Teachers, like young students (Mehrotra & Khunyakari, 2007), emphasized aesthetic aspects of their models. Ice cream sticks were put to different uses: roof supports, for a bamboo element, and for staircases. Several groups annotated their sketches with materials and elements to be included in the construction. Most groups considered ecological concerns, like conservation, recycling, vermi-composting, rain-water harvesting, solar panels and windmills, as the highlights of their designs.

Need for additional inputs: Designing and making is based on pre-existing conceptual knowledge. However, lack of visualization and representation skills can constrain design. However, teachers of different subjects participating in the workshop had difficulty visualising 3-D structures, calculating dimensions of their complex structures from given area and making elementary technical drawings. In an earlier study among middle school students, tasks involving technical drawing skills, representations of 3-D objects on paper, and sewing preceded designing and making puppets (Mehrotra & Khunyakari, 2007). Barlex (2006) refers to tasks that provide pre-requisite knowledge and skills for an activity as resource tasks. Such tasks could not be included in the limited time available in the workshop. Perhaps, future design and make activities with teachers needs to be preceded by such resource tasks.

Conclusions and Implications

The educational advantages of engaging students in hands-on activities has been emphasised by educational philosophers like Dewey and Gandhi. In the words of Gandhi (1968, p. 434), "True education of the intellect can come only through a proper exercise and training of the bodily organs... A proper and all-round development of the mind, therefore, can take place only when it proceeds *pari passu* with the education of the physical and spiritual faculties of the child." However, this aspect is still largely missing in students' educational experiences in Indian schooling (Kumar, 2004). While it is important to work towards introducing opportunities for design thinking in schools, this cannot be achieved through teachers, who have never experienced such activities. The workshop on *Thinking through Design* explored teachers' responses to a short exposure to such activities.

In the workshop, teachers of different subjects were introduced to design and technology education, given a design brief and supporting information. Over a few hours, they worked in groups to visualise their design solutions and represent their ideas. The activities required teachers to draw knowledge from different subjects, engage in quantitative reasoning and estimation, making sketches and models. They also had to reflect on their activities. Their responses to questions revealed that teachers could recount several educational goals and learning objectives of design activities, though the learning objectives were not linked to school subjects like science, geography or mathematics. Teachers are rarely required to reflect on learning objectives, which are provided in the syllabus. This suggests that teachers need opportunities for reflecting on links between learning objectives and teaching sessions.

Teachers cited their earlier science projects, art and craft work, etc. as being similar to design activities. However, when asked to describe a design activity that they would now carry out with their students, they wrote about designing energy saving lamps, staging Egyptian puppet play, and making eco-friendly mathematical or science models. In fact, environmental sustainability was seen as a concern in the design productions of the groups as well.

Analysis of the sketches and model revealed that quantitative reasoning and estimation as well as representing their visualisations were challenging for the teachers. Calculating the length dimensions of the plot from the given area and representing these on their sketches were the most difficult. They used several strategies to convey their design ideas and their concerns. The activity space for students designed by the 6 different groups using the skills of its members, varied in shape of plot occupied, height of structure, partitions and structural materials, as well as activity requirements and other aspects. Helping teachers appreciate design thinking and its educational benefits requires sustained interactions and workshops over a long period of time. For instance, it would be interesting to study the time and effort spent by teachers in exploring the design problem and alternative solutions, once they are exposed to resource tasks on basic skills of sketching and representing 3-D ideas on paper.

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