COMPARISON OF DEPICTIONS BY MIDDLE SCHOOL STUDENTS ELICITED IN DIFFERENT CONTEXTS

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Abstract

Drawings are important in design and are a major part of technological activity. This paper presents analysis of drawings produced by Indian middle school students in different contexts: while designing in a D&T task, translating textual information to depiction, and while depicting the solution to a problem stated in text. The tasks included drawing of simple and complex, static and dynamic objects. In all tasks students used exploratory sketches and several strategies to translate their ideas of 3-D objects on to paper (2-D): perspectives, graphical symbols (lines, circles, etc), selective abstraction, X-ray drawings, etc. Depictions of assembly had more annotations than depictions of static and assembled objects themselves. Explorations in the design context were more than in any other context. There is a need for incorporating activities in school curricula, which can enrich students' drawing and visualisation skills. The findings suggest that design and technology education units could encourage such activities.

DRAWINGS IN TECHNOLOGY AND EDUCATION

As part of our everyday activities, we manipulate and maintain technological objects. This offers scope for visualisation of relations between structures of artefacts and their functions. We refer to artefacts in our interactions using verbal and non-verbal communication modes, which may include talking and gesturing, verbal descriptions, reading and making drawings. Such communication and thinking with drawings and pictures has been an essential strand in the intellectual history of human development in general and technological development in particular (Ferguson, 1977).

Visualization and externalization of objects

We often understand the diverse objects around us through our knowledge about their spatial and functional distinctions from other objects. It is known that expressing ideas in a visuospatial medium, such as drawings, photographs, models, etc., makes comprehension and inference easier than in a more abstract medium such as language (Tversky, 2002). Drawings aid in the development of reasoning and problem solving skills, and cut across disciplines.

Drawings are preferred over textual representations for externalising and sharing of ideas among designers, architects and engineers. Whereas text is serial in nature, drawings explicitly preserve information about object geometry and topology (Ullman, Wood and Craig, 1990). Besides, they can be used to convey the dynamics of objects and their assemblies (Hegarty, 2004). Literature reveals that adults use sketches and drawings as an aid to thinking (Suwa and Tversky, 1997; Scrivener, Ball and Tseng, 2000). Designers have been noted to make sketches that are tentative, vague and incomplete (exploratory sketches). For children, drawings are a spontaneous form of expression (Ramadas, 1990). Like designers, students also use drawings to think, visualize and reflect on their ideas, especially when engaged in problem-solving (de Bono, 1972) and design (MacDonald and Gustafson, 2004; Hope, 2000). Preliminary design ideas are explored by students through sketches. Sketches give us insight into the strategies used by students to visualize and manipulate their ideas of objects and assemblies in different tasks. Anning (1997) has emphasized the role of graphicacy as a tool for learning and recording thinking in classrooms. However, present teaching practices from the primary through high school, either in drawing as a subject or drawing as an aid to learning other subjects, fail to encourage drawing as a mental (cognitive) engagement.

Drawings of objects and assembly in different contexts

Drawings based on oral or textual descriptions may differ from those that emerge from contexts such as in design, where drawings emerge without reference to an already existing tangible object, drawing or textual description. Drawings may be of simple objects, symmetrical shapes, or complex objects as in a multi-component dynamic system. Reasoning about assembly and dynamic mechanical systems involves visualisation of the location of objects, their shapes and spatial connectivity (Hegarty, 2004). In the design context, there are no right or wrong drawings: sketches represent explorations of ideas, while drawings represent the visualised design.

Students' understanding of a concept (dog, pair of scissors) is based on their judgements of its structural and functional attributes, and their own experiences. Their depictions may reflect the associations that they spontaneously make with the word (Natarajan et al, 1996). Drawing an assembly of objects based on textual descriptions and cues involves verbal understanding and its translation to spatial depiction, in which both spatial and verbal abilities play important roles. The description could have all the details of artefact(s) to be drawn in the textual form and require students to interpret the text, visualise and depict the artefact on a paper. The depictions may match the description to a lesser or greater extent, reflecting students' textual comprehension, imagery and depiction skills.

Objectives

The study is based on middle school students' paper-pencil productions in two experiments carried out at different times that explored middle school students' representations of simple and complex, static and dynamic objects in three contexts. The following questions are addressed here:

1. How do different kinds of objects and contexts influence exploratory sketches?
2. What aspects of the description do students represent in their drawings and what ideas do they use to depict an object?

METHODOLOGY

The data used in this study comes from the productions of students in two experiments given below.

Experiment 1 – Design context

The trials of a Design and Technology (D&T) unit required groups of students to design and make a windmill model that can lift a given weight. Details of the trials are discussed in an earlier paper (Khunyakari et al, 2007). Students worked collaboratively to design their group's windmill model for about 2.5 hours, making exploratory sketches (tentative and incomplete), technical drawings (dimensioned finished product) and procedural maps (plan of making).

Experiment 2 – Depictions from textual descriptions

The experiment involved two tasks set in two different contexts (see Figure 1): (i) *depicting objects based on textual description* followed by (ii) *depiction of a solution to a problem stated in text*. The tasks were completed in 1.5 hours. Students could use as many sheets of paper as needed for making exploratory sketches (tentative) and final drawings. The responses to the first task were collected before administering the next.

Sample

This study was in a socio-cultural setting, where students had different home languages and English as medium of instruction in school. Within the setting, students' willingness to participate in the study, the proximity of the school to researchers' institution and the existing rapport with the school management influenced the selection of the school and sample.

The sample for the design activity in Experiment 1 was 19 students (9 girls, 10 boys), who had just completed Grade 6 (about 12 years). The activity involved students working in 6 groups: 2 groups of girls, 2 of boys and 2 mixed sex (boys and girls) groups.

The sample in the second experiment on depicting objects from text consisted of 60 students (21 girls and 39 boys), who had just been admitted to Grade 8 (about 13 years). Students responded individually to the two tasks set in this context.

Task 1: Ramu is a car mechanic, who has studied only till Class 3. One day, his supervisor gives him a list of items, which he has to buy or assemble. Ramu shows you the list and asks you what is written in the list. Make drawings of each item in the list for Ramu, so that he can know what to bring and assemble.

Item 1: One 100 mm long solid metal cylinder of diameter 20 mm

Item 2: One 150 mm long hollow PVC pipe of inner diameter 25 mm and outer diameter 30 mm

Item 3: The solid metal cylinder (Item 1) has been placed inside the hollow PVC pipe (Item 2).

Task 2: On her way from the vegetable market on her bicycle, Lata's bicycle chain suddenly came off. Lata started to walk home. Imagine that she met you along the way and asked you about the assembly and working of a bicycle chain. Draw a diagram to explain to Lata the assembly and working of the chain and pedal arrangement in a bicycle.

Figure 1: The two tasks in Experiment 2

ANALYSIS

Students' responses on Experiment 1 and the two tasks of Experiment 2 were in the form of paper-pencil productions. The following aspects were used to analyse and compare students' productions in the three task contexts.

Visualisation and meanings

- *Extent of explorations:* The number of students' explorations for parts and assembly in each task was recorded and compared across tasks.
- *Spatial attributes:* For Experiment 2, space was provided for the date and student's name at the top of each rectangular sheet of paper in the portrait mode. Students maintained this orientation of the page in their drawings, which served as reference for vertical orientation of their productions. Depictions of objects and assemblies in vertical (longer dimension perpendicular to the baseline), horizontal or along any other direction were recorded.

Graphicacy skills in depictions

- *Dimensions and drawing conventions for static and dynamic objects:* Labels, annotations or conventions like leaders, arrows and end lines to depict dimensions in drawings were noted as well as the students' depictions reflecting the relative dimensions given in the text (length, diameter, etc.) and relative proportion of assembled parts (spiked wheels, pedals, etc.). It was important for students to include dimensions in their technical drawings and procedural maps in the design context and in Task 1 of Experiment 2. Dimensions were not relevant to drawings in the bicycle chain problem in Task 2.

- *Perspectives and translating from 3-D to 2-D:* Strategies and perspectives used by students to depict 3-D objects in the two experiments are compared qualitatively. Students' choice of perspectives in the design task gave an idea of the richness of strategies used by them for depicting 3D to 2D. For the other tasks in Experiment 2, perspective was less relevant and was only noted for its variety.

VISUALISATIONS AND MEANINGS

Students' visualisation of space is seen through the depiction of 3-D objects on paper. Though all the three task contexts concerned geometric objects and their assemblies, different contexts stimulated different strategies for visualisation and depiction. In the D&T unit, students conceptualized and designed the windmill model that they would later make. As their design progressed, the object became intimately familiar to them and they engaged with the details of the assembly. All groups drew one or more drawings to show the 3-D aspects of their windmill model.

For the task on cylinder and pipe, the dimensions and materials were given in the text. They were contextualised and students had to visualise the object descriptions for someone else. Students' drawings corresponded to the object described in the text (e.g. a dimensioned solid cylinder) or an imagined one not corresponding to the description (e.g. a cooking gas cylinder or measuring jar).

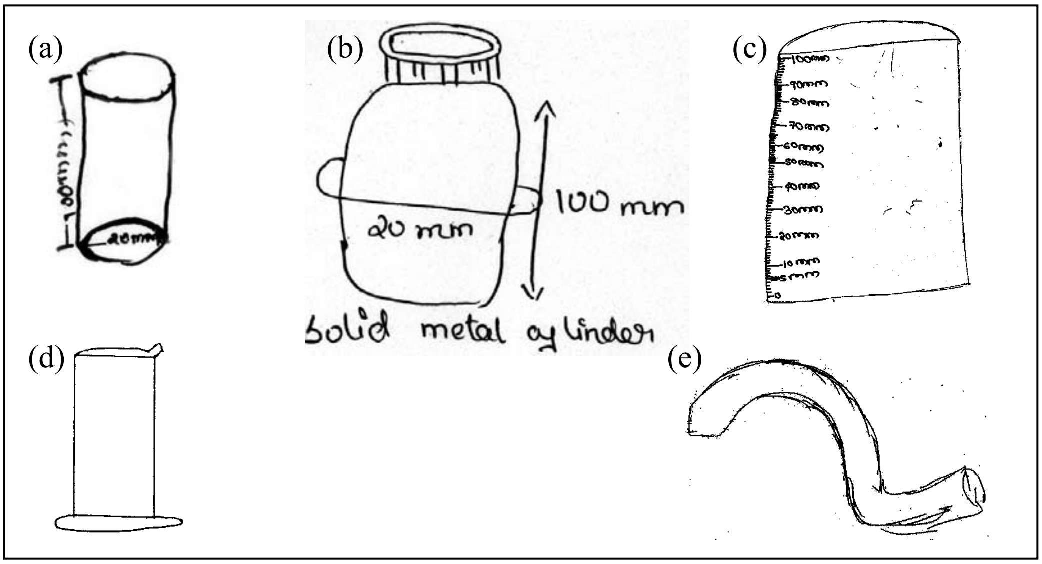

Figure 2: The phrase "a solid metal cylinder" triggered association with (a) a geometric object, (b) a cooking gas cylinder, (c) graduated vessel and (d) measuring cylinder (e) shows a student's depiction of "hollow PVC pipe"

A fifth of the sample in the cylinder and pipe task spontaneously associated meanings and attributes of familiar objects with the textual information. The word "cylinder" triggered depictions of a cooking gas cylinder or a measuring cylinder among these students. A "150 mm long hollow PVC pipe" was drawn as a long thin flexible pipe.

A few students spontaneously used analogies while depicting objects, especially in problem solving contexts, which came up both while designing the windmill and in the bicycle task. In the windmill design, the structure of star inspired the vane assembly, or a tripod was refined to the tower. In the bicycle task, an annotation described "…the chain works like a rope".

Extent of explorations

In the design context, groups negotiated the design problem and discussed potential solutions. Groups had to think of the structure, assembly and functional aspects of their windmill model, decide materials, and estimate dimensions. Complex assemblies of components involving a number of parts elicited more exploratory sketches than did simple components. Perhaps, visualizing a non-existent artefact intended for making required students to explore the details of parts and their assembly. Students used sketches as a means to ideate and visualize these details.

While translating textual descriptions to depictions in the cylinder and pipe task more than half the students (34 out of 60) made exploratory sketches of objects and assemblies, possibly because of the unfamiliarity of the task and the abstract object referred. Correspondingly, there were fewer exploratory sketches (26 out of 60 students) in the bicycle chain problem solving context. Though it involved a complex dynamic assembly, the artefact and its textual reference were both familiar and unambiguous.

Spatial attributes

Did students have preferences in orientation for depicting objects of different shapes and in different contexts? In the context of design, the orientations of parts of the windmill model were decided by their place in the assembly: a cylinder or tube was shown horizontal when used as an axle and vertical when used for support. However, while translating textual information into drawings, students tended to depict the solid metal cylinder as vertical (45 out of 60) and PVC pipes as horizontal (36 out of 60).

When faced with the challenge of depicting an assembly of these two items, the largest number of students (27 out of 60) showed one object suspended inside the other with no physical contact between the two. Some (6) chose to depict the solid metal cylinder projecting out from the hollow pipe, sometimes at both ends, not taking into account the cylinder's smaller length.

GRAPHICACY SKILLS IN DEPICTIONS

Graphicacy involves the use of skills to represent ideas or objects, which is studied here in terms of the dimensions and conventions used in depictions, as well as perspectives and strategies used for translating 3-D objects to 2-D. The exploratory drawings were rich with graphical symbols and elements used for multiple purposes. While designing, students used graphical symbols to represent different structural and functional attributes. For example, circular lines around vanes were used to show motion (see Figure 4a).

Dimensions and conventions in depictions of static and dynamic objects

Drawing conventions and dimensions were relevant to the technical drawings and procedural maps in the design task as well as to the drawings in the cylinder and pipe task. Students, who participated in the D&T unit trial, had been exposed briefly to techniques and conventions for depicting dimensions and units. A majority of groups (4 out of 6) included dimensions and units using conventions in the depiction of their windmill model. Besides, they chose to make drawings proportionate to the dimensions shown (Figure 3a). This was possibly because they intended to make, and hence had visualised the details relevant for making.

Students participating in Experiment 2 had no exposure to the conventions of showing dimensions in drawings. While translating the detailed descriptions of a cylinder and pipe into depictions, the given dimensions were reproduced as textual labels (Figure 3b), if used at all. In depictions in Task 1 (Experiment 2), a few students indicated the process of assembly using a dotted line and an arrow (Figure 4b). Dimensions and units given in the text were crucial for the assembly to be depicted as in text. Yet, proportionality of length and diameter in the drawings were triggered only among a fourth of the students. Students seemed to be guided by the relational word, e.g. “inside”.

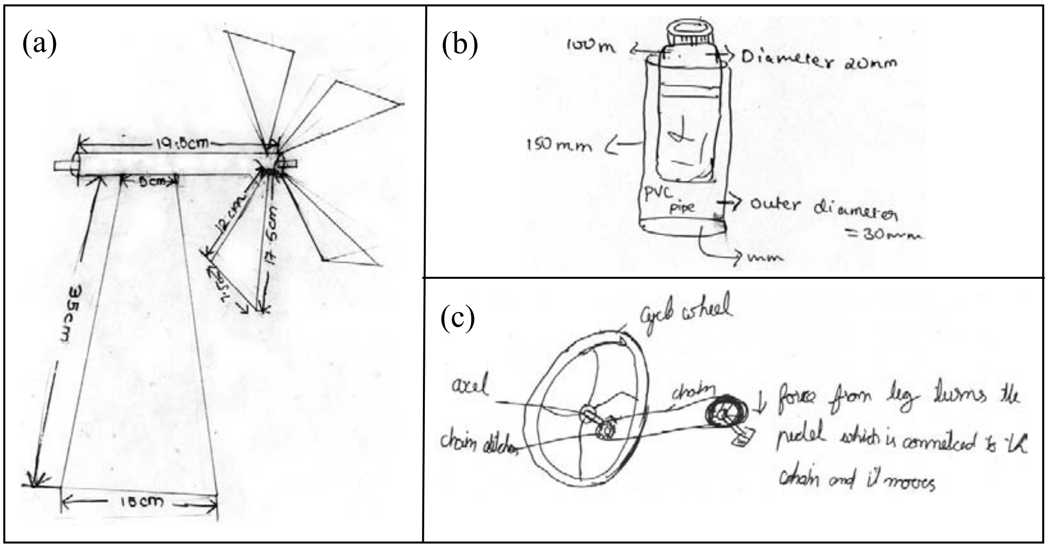

Figure 3: Students depict dimensions and units (a) using conventions in the windmill design, (b) as labels in the cylinder and pipe task and (c) use annotations in bicycle chain assembly task.

Solving the bicycle problem in Experiment 2, Task 2 required students to engage in mechanical reasoning, of putting the chain on the spiked wheel and rotating the pedal slightly. Two thirds of the students showed this in their drawings. About a third of students (17 out of 60) supplemented their drawings with annotations of the procedure at each step (Figure 3c). About a third chose to draw the entire bicycle. A significant proportion of students maintained the relative proportion of objects in the assembly: of the 33 students who drew the 2 spiked wheels, 24 showed them in the correct proportion as commonly seen in bicycles in India. At times, students enlarged features like the pointed tooth of the spiked wheel to highlight it. Students variously depicted the chain by lines, wavy lines, unconnected but closely arranged circles or circles connected by small lines. Among the 60 students, 14 tried to indicate motion in the assembly with the help of lines and arrows. In some cases, an arrow or icon of a hand over the pedal indicated the direction of force.

Perspectives and translating from 3-D to 2-D

Perspectives as a strategy for depicting the 3-D nature of objects on a 2-D paper varied with the nature of the object – simple or complex structure, symmetric, composite, etc. – and the choice of part or view.

In the design context, where students had to visualise a non-existent complex dynamic object in 3-D and represent it on 2-D, students made choices of different perspectives while they explored, made technical drawings and procedural maps. They used a variety of strategies like dotted lines or X-ray drawings of occluded parts, and icons for those parts that obstructed showing details of assembly (selective abstraction of axle and vanes in Figure 4a and chain in 4c). A few groups showed the windmill design details by depicting the front, lateral and back views.

For the tasks in Experiment 2, where students had to draw simple objects, perspective was less relevant. However, it was interesting to see that students spontaneously used perspectives even in these tasks. Task 1 in Experiment 2 involved simple, largely symmetric static objects – solid cylinder and hollow pipe – and their assembly. About half the students (31 out of 60) depicted both the circular ends of the cylinder and pipe (see Figure 2a). These students had not been exposed to technical drawings, and perhaps they were trying to show every detail (intellectual realism). Most students resorted to X-ray views: in the bicycle task and to show the assembly of a cylinder inside hollow PVC pipe. In the bicycle repair task, students faced difficulty in showing the pedals perpendicular to the spiked wheel. Though most drawings showed lateral views, some students attempted an aerial view to overcome the problem.

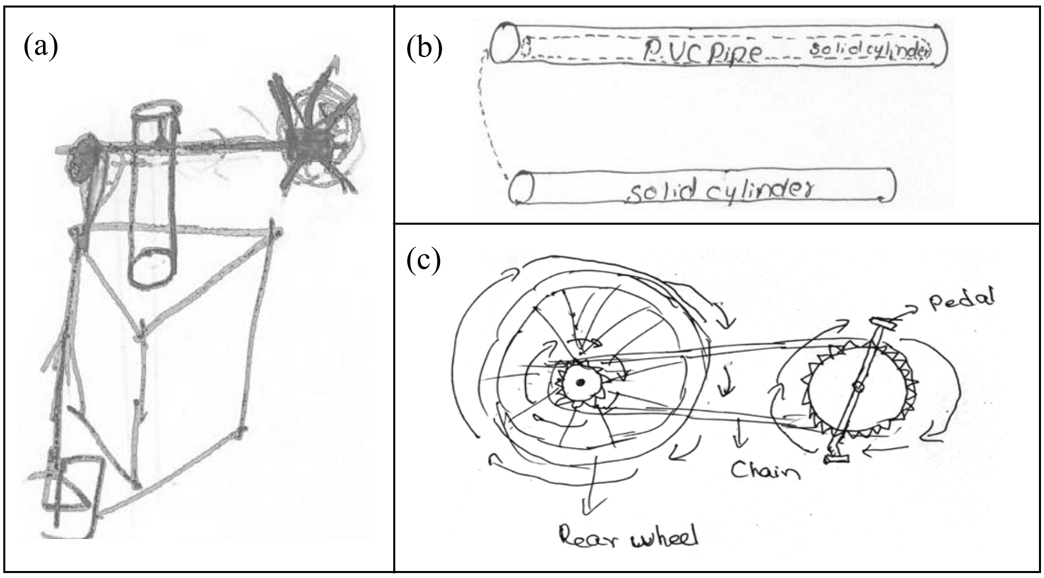

Figure 4: Depiction of motion in three contexts: (a) in a windmill model, (b) assembly of a cylinder and pipe; and (c) bicycle chain assembly.

CONCLUSIONS

This study used activities in two experiments, which engaged students in drawing simple and complex, static and dynamic 3-D objects set in three task contexts. The task contexts included designing a windmill model as part of a D&T unit, translating textual information to depiction, and depicting the solution to a problem stated in text. The study aimed to see if different kinds of objects and task contexts had an effect on the extent of exploratory sketches and the aspects of description represented by students in their drawings. Students' visualisations of objects and the meanings they attributed to textual descriptions were analysed and students' preferred orientations of objects were noted. Graphicacy skills in depictions were analysed in terms of students' use of the dimensions, conventions and strategies used for drawing static and dynamic objects.

Students' spontaneous ideas influenced their visualisation of objects and drawings in the three contexts in different ways. Design visualisations, which were generated by the students working as a team gave rise to the largest number of exploratory sketches among all tasks. Several needs – to share one's design with other group members, memory offload and ease of manipulation of an external representation – all may have led to this increase in explorations. The sketches often evolved from doodles that suggested analogical transfer from known objects to newly conceptualised design. Descriptions of abstract objects had fewer explorations, and a problem solving context involving a familiar artefact had the least exploratory sketches.

The different task contexts stimulated different strategies for visualisation and depiction. Students tended to show a solid cylinder in a vertical orientation when drawing from description. However, the context decided the orientation – either horizontal or vertical – while depicting cylinders in assemblies. Students used multiple perspectives and made use of X-ray drawings. They used graphical symbols like circular lines or arrows to indicate motion or the direction of movement. Students who participated in the D&T unit trials were briefly exposed to technical drawings, which led to their use of conventions in indicating dimensions and units.

The results of the tasks in different contexts reiterate the use of drawings as a potential medium for visualisation, comprehension and exercise of skills and techniques in depicting ideas about objects and assemblies. Technology is largely perceived as objects by middle school students (Mehrotra et al, 2003) and our understanding of the artefactual (technological) world can be aided by drawings. It is hoped that exposure to complex and dynamic assemblies can help students to go beyond the technology-as-object perception.

The study suggests that present school curricula have not equipped students to translate textual description of artefacts to drawings. However, students have the ability to visualise complex and dynamic artefacts and make drawings as seen in the design and bicycle chain problem solving task. In order to train students in drawing from text and using the diagrams supplementing text, making drawings in different contexts of tasks – design, problem solving and abstract descriptions – needs to be integrated into existing school curricula at all stages.

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References

Anning, A. (1997). Drawing out ideas: Graphicacy and young children. *International Journal of Technology and Design Education*, 7, 219-239.

De Bono, E. (1972). *Children solve problems*. Allen Lane Penguin Education, England.

Ferguson, E. S. (1977). The mind's eye: Nonverbal thought in technology. *Science,* 197(4306), 827-836.

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

Hope, G. (2000). Beyond their capability? Drawing, designing and the young child. *Journal of Design and Technology Education*, 5(2), 105-114.

Khunyakari, R., Mehrotra., S. Chunawala, S. and Natarajan, C. (2007). Design and technology productions among middle school students: An Indian experience, *International Journal of Technology and Design Education*.http://www.springerlink.com/content/g301p8519840475m/?p=123b9c714f614181a3de7b7c55b1637c&pi=18

MacDonald, D. and Gustafson, B. (2004). The role of design drawing among children engaged in a parachute building activity. *Journal of Technology Education*, 16(1), 55-71.

Mehrotra, S., Khunyakari, R., Chunawala, S. and Natarajan, C. (2003). *Using posters to understand students' ideas about science and technology*. Technical Report No. 1(02-03), Homi Bhabha Centre for Science Education, Tata Institute of Fundamental Research, Mumbai, India.

Natarajan, C., Chunawala, S., Apte S. and Ramadas, J. (1996). *Students' ideas about plants. Diagnosing Learning in Primary Science (DLIPS) Report – Part 2.* Technical Report No. 30. Homi Bhabha Centre for Science Education, Tata Institute of Fundamental Research, Mumbai, India

Ramadas, J. (1990). Motion in children's drawings. In Idit Harel (ed.). *Constructionist learning*, The MIT Media Laboratory, Massachusetts, 249-280.

Scrivener, S., Ball, L. and Tseng, W. (2000). Uncertainty and sketching behaviour. *Design Studies*, 21, 465-481.

Suwa, M. and Tversky, B. (1997). What do architects and students perceive in their design sketches? A protocol analysis. *Design Studies,* 18, 385-403.

Tversky, B. (2002). What do sketches say about thinking? In Stahovic, J. Landay, and R. Davis (Eds.), *Proceedings of AAAI Spring 2002 Symposium on Sketch Understanding*, Palo Alto, California: AAAI Press.

Ullman, D. G., Wood, S. and Craig, D. (1990). The importance of drawings in the mechanical design process. *Computer and Graphics*, 14(2), 263 – 274.