Middle School Students' Knowledge about Static and Dynamic Artefacts Studied through their Drawings and Descriptions

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This paper reports a study of students' understanding of artefacts through their drawings and descriptions. The experimental design of the study carried out with 12 middle school students (ages 11- 13 years) involved four stages: pre-test, intervention and post-test, followed by a semi-structured interview of each student. The intervention activities engaged students in filling a questionnaire by estimating and measuring dimensions of a variety of artefacts of common shapes and sizes, writing their descriptions, and in repairing a bicycle. The study analysed students' paper-pencil productions in the tests and the questionnaire, and audio and video data collected during the intervention and interviews. The effect of the intervention on the nature of depictions of proportions and dimensional attributes in the drawings depended on the context of problem solving. Interviews helped to make explicit the meanings ascribed by students to the descriptions and the strategies used by them in their object depictions. The study highlights the importance of engaging students in authentic contexts of problem solving, and making drawings in such contexts.

Introduction

Knowledge of technology is about understanding artefacts and their relations. Understanding and knowing about structure, function and arrangement of artefacts and their interactions is the core of technological literacy (de Vries, 2005). Coherent knowledge about artefacts comes through sustained and dialectical human-artefact interactions (Ihde, 2006). Integrating aspects of technological literacy in general education provides a space to engage the learner in designing, making and improvement of artefacts for human benefit. Such learning prepares students to be critical and active recipients of technology (Pitt, 2006).

Drawing serves as an external token to reduce the visual complexity of object structures and their manipulation when it is articulated in the mental space. Children use drawings to converse, generate ideas (Anning, 1997) and solve complex problems (de Bono, 1972). Designing involves translation of human needs to a desired outcome. As a tool for enquiry and a method of external representation, drawings play an important role in design, which is the heart of technological activities (Ullman et al., 1990, Khunyakari et al., 2007a). However, the role of drawings in design and cognition has not yet been fully explored. A precursor to this study explored Indian middle school students' depictions of static and dynamic objects (Selvaraj 2007). This study probes deeper the depiction strategies that stu-dents use to represent mechanical objects and systems based on verbal descriptions and cues. The two tasks used in the tests in this study are the same as those used in the exploratory study.

Objectives

The study addresses the following questions: (1) When asked to estimate and measure the size dimensions of artefacts, how closely do students' estimates match their measurements for small and large dimensions? (2) What aspects do students use to describe abstract artefacts of common shapes, sizes and materials, and to depict a familiar bicycle? (3) In what ways do handling, estimation and measuring activities influence students' depictions?

Sample

Twelve middle school students categorised as two groups (Group A and B) participated in this study. Six (3 girls + 3 boys) students of Group A were selected from among the

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 comes off. Lata starts to walk home and meets you along the way. She asks you about the assembly and working of a bicycle chain.
Draw a diagram to explain to Lata the assembly and working of the bicycle chain and pedal arrangement.

Fig. 1. The two tasks in the pre- and post-tests.

60 students who participated in the exploratory study and the six (3 girls + 3 boys) students of Group B were selected from another similar school run by the same institution. The only difference between these two groups was that the Group A had been exposed to object drawings in earlier experiment whereas Group B had not received any exposure.

Research Design

The experimental research design involved four stages: pre-test, intervention, post-test followed by semi-structured interviews. The experiment involved a one-to-one interaction of each student with the researcher for about 2.5 hours. The study was completed in two weeks.

Pre- and Post-tests

Students were presented with the same two tasks in both the tests. Task 1 required students to depict as drawings the given description of simple and static objects and their assembly. It included shape, dimensional and material information. Task 2 was a context that required the drawing of working of the chain and assembly of a bicycle, a familiar but complex and dynamic mechanical object. It had no explicit dimensional cues. The tasks are given in Figure 1. Each task required them to read, comprehend, interpret, visualize and draw objects and their assembly. In each test, students took about 25 minutes to complete both the tasks.

Intervention

The intervention involved students first handling 10 artefacts (named A, B, C...) of common geometric shapes and sizes that varied from 2 mm to 1360 mm. They were told, "You are given several objects. Handle each one, estimate its size and measure its size. Measure as many different lengths as you need, to describe each object fully. Describe it in two lines." Measuring instruments included ruler, measuring tape and cotton thread. Table 1 shows a student's response to two of the given artefacts in the questionnaire. Note that this activity did not engage students in drawing objects. The artefact activity, which took about 45 minutes to complete was followed by the bicycle activity. The student had to list the parts of a bicycle chain assembly and replace the fallen chain on the spiked wheel of the bicycle to make it functional again. This activity took about 15 minutes to complete. If the student failed to replace the chain after trying for about 10 minutes, s(he) was shown how to do it.

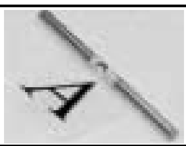
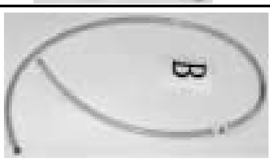
Object	**Sizes: estimated & measured** Length = L, Height = H, Breadth = B, Diameter = D, Inner diameter = ID, Outer Diameter = OD		**Descriptions**
	Estimation: H = 10 cm, D = 0.90 cm	Measured: H = 10 cm, D = 0.60 cm	This is made up of metal (iron) it is a kind of enclosed heavy cylindrical pipe. Metal can mould and make the driving part of a screw driver.
	Estimation: ID = 2.5 mm OD = 5.0 mm H = 70 cm	Measured: ID = 3.0 mm OD = 5.0 mm H = 77.5 cm	It is a bendable plastic pipe, which is very thin and can be used to carry vaccine from vaccine bag to hand of patient.

Table 1. A student's responses to two of the given artefacts in the intervention questionnaire

Interview

The productions of pre and post tests were drawings. Semi-structured interviews conducted with students after the post-test probed students' reasons for choosing a depictive strategy in their drawings and about the bicycle parts and its working.

Data and Analysis

The data was collected from productions in the pre- and post-test productions and intervention questionnaire, and audio and video recordings of interventions and interviews as well as in the form of researchers' observations and notes before, during and after the sessions. Students estimated a total of 28 dimensions for the 10 artefacts.

Students' descriptions of objects were analysed using ATLAS/Ti software based on the following scheme of categories. Category level 1 consisted of structure, function, associations and concept terms. The structure descriptions could be either of topology or morphology. Topological descriptions could be about configuration and internal shape, about the material of the artefact or about its property. The morphological descriptions could refer to gross shape, qualitative or quantitative aspects of size. Using the software for text analysis, the number of such items from each student's description of each of the 10 artefacts was counted. Table 1, which tabulates the results, also gives examples of each category of description. In the bicycle activity, the numbers of parts mentioned by students were noted.

Proportion is the relationship between dimensions (e.g. horizontal – vertical) (Laseau, 2000). It also refers to the nature of space (form) occupied by an object with reference to another object. In the pre- and post-test drawings of Task 1, the proportion in the depiction of the solid metal cylinder by each student was noted in terms of the ratio of its length to its diameter (value given = 100/20 = 5). For the hollow pipe (Item 2), the ratio of its length to its outer diameter was noted (value given = 150/30 = 5), while the assembly proportion was noted in terms of the ratio of the lengths of the outer hollow pipe to the inner solid pipe (given value = 150/100 = 1.5).

The audio recordings of interviews were transcribed to study students' justifications for use of visualisation and depiction. Researcher's cues during the interview that triggered a change in students' drawings were also noted. The text and interview transcripts of bicycle chain assembly were analysed to note evidences of students' reasoning about the structure and function of the bicycle as well as the analogies and associations they draw upon.

Results and Discussion

The analysis of the estimation and measurement of artefact dimensions are reported here, followed by a report of the proportions of items in Tasks 1 and 2 in students' drawings in the pre and post tests. Results of a quantitative analysis of the categories in students' description during the intervention are discussed. The nature of justifications given by students for their depictions and students' reasoning about the working of a bicycle in response to researcher's cues are illustrated by an example of each from the transcripts.

Estimation of Dimensions

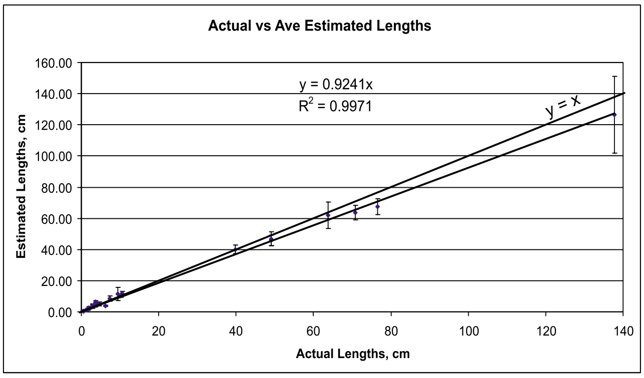


Fig. 2. Relation between actual (measured) and mean estimated dimensions.

Students used different strategies to estimate the size of given objects: fingers or palm spans were used to measure smaller and larger lengths respectively. Three students estimated the size in their "mind's eye". Students' measured values of the dimensions closely matched the measurements by the researchers, and are referred to here as "actual value" of those dimensions. The mean value of 12 students' estimations of each of the 28 dimension was tabulated against its "actual value" and these were arranged in ascending order of values of lengths. These were used to obtain the scatter plot shown in Figure 2. The standard deviation of each mean estimated value indicates the error of the mean estimated value in the plot.

A linear regression trend line through all the points showed a slope = 0.92 and R2 = 0.997, indicating that in general students marginally underestimated lengths, especially the dispersed lengths greater than 30 cm, which dominated the plot. However, the linear regression trend line was also obtained for a plot of all values of actual lengths less than 30 cm, shown in Figure 3. The slope of this trend line = 1.11 (with R2 = 0.873) indicates that students tend to overestimate the smaller lengths.

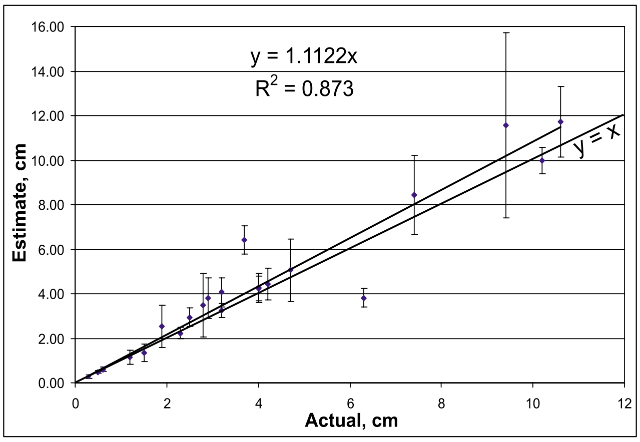


Fig. 3. Relation between actual and the average estimated length of <30cm.

Proportions in Pre- and Post-Test Drawings

There were more differences between pre- and post-test drawings for some items and not for others. The effect of the bicycle activity during the intervention was seen more in the post-test Task 2 drawings of Group B students than in the drawings of Group A students.

In the case of Task 1 drawings, there were no notable differences between the pre- and post-test drawings of static geometric objects in items 1 and 2 for most students of either group. Only a few drawings showed proportions (both items have length to radius ratio of 5) either in the pre- or post-test. However, for the assembly item 3, about half the students depicted the relative lengths of the two as-sembled objects in proportion (ratio of length of hollow pipe to length of solid cylinder = 1.5) in the pre-test. In the post-test, two more students had drawn the assembly in correct proportions of the lengths of the two objects. Perhaps considerations of the relative proportions called for while drawing the assembly of the two objects triggers drawing them in proportion of lengths (see Figure 4).

The drawing of geometric objects makes a demand on students' visuo-spatial skills. Assembly of two or more 3-D objects requires students to estimate the sizes of the objects and visualise their relative sizes, before mentally manipulating one object in relation to the other. Thus a whole body of spatial and mathematical skills are needed to visualise and depict an assembly of objects. It has been found that context plays an important role in the use of these skills. In a study, students engaged in designing tasks, which were closer to authentic situations, were found to draw all parts of an envisioned artefact in correct proportions, even labelling the dimensions of the parts. (Khunyakari et al., 2007b.).

The case of Task 2 was different. For one no dimensions were specified. The parts had to be drawn in proportion to indicate a familiar and useful artefact. In this case, it was a question of understanding and depicting the structure-function relationships. Group A students, who had already done this task once before the pre-test did not change their drawings from pre- to post-test in this experiment. The intervention had no effect on their drawing. However the depiction of parts and working of the bicycle chain and pedal assembly improved from pre- to post-test for students from Group B, who depicted only the parts which were necessary to show the working of the chain and pedal assembly in their post-test drawings (See Figure 5).

Nature of Descriptions of Artefacts

Frequencies of occurrence of description categories in students' description of objects in the intervention activity are given in Table 2. The table also gives the categories used and examples of students' descriptions that fall in each. The frequency pattern obtained through ATLAS/Ti shows

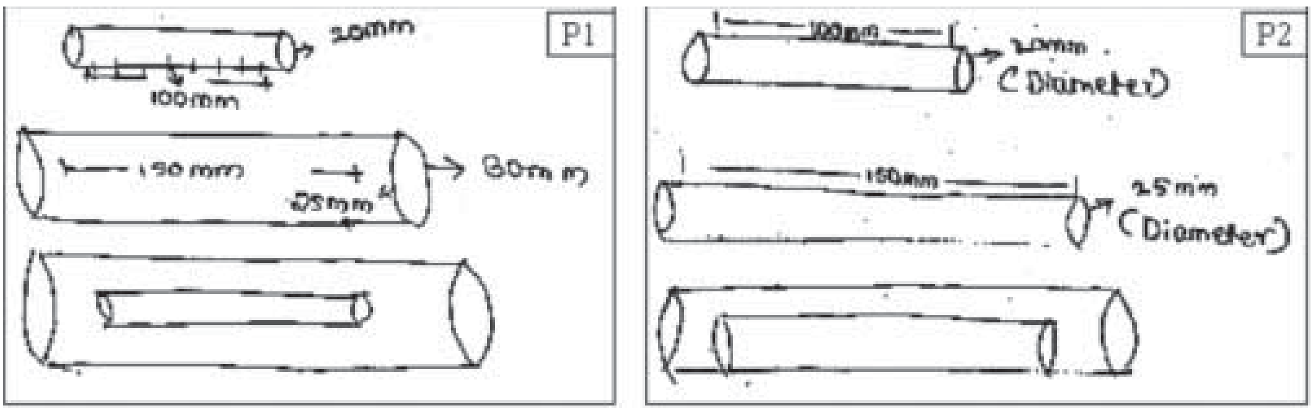


Fig. 4. Pre- (P1) and post- (P2) test drawings of a student showing improvement in proportion of assembly, but less in the drawing of individual items

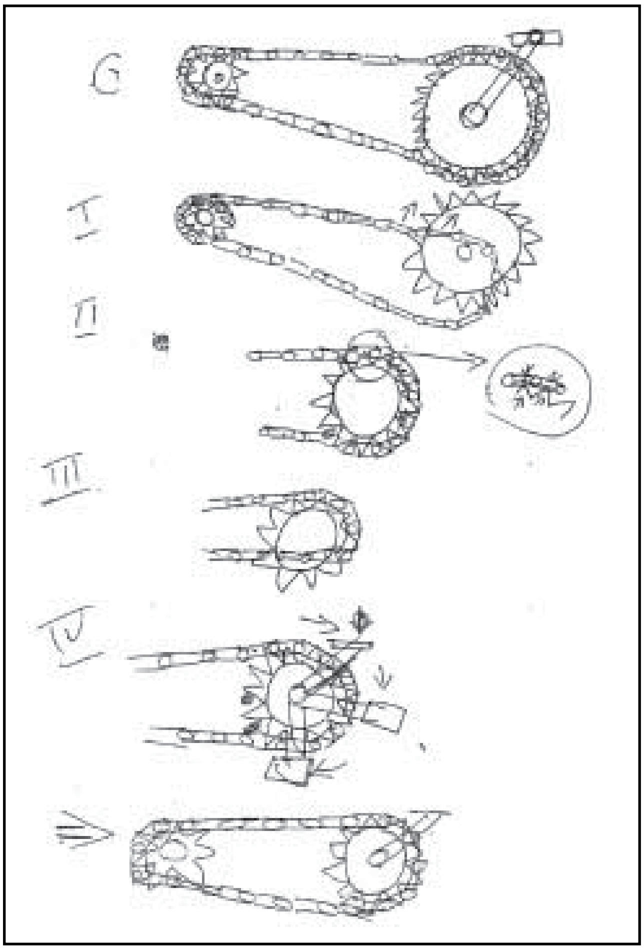


Fig. 5. A student's depiction of how to place the chain back on the spiked wheel.

that students mostly described artefacts in terms of structural aspects of topology (153 instances of a total of 361 instances from 120 object descriptions) and morphology (123 instances), and less in terms of functions (30 instances). The largest number of instances was of material, followed by the artefact's gross shape, quantitative dimension and configuration. The relatively large frequency (50) of quantitative sizes indicates the effect of the most recent activity of measurement, which either does not last till the post-test drawing task half an hour later or does not seem applica-ble in the drawing context. They also used common conceptual terms such as, "pipe" for hollow cylinder (36 times), "tube" for flexible cylindrical hollow ob-jects and "rod" for solid cylindrical objects. Often they used these words with adjectives such as hollow pipe, plastic pipe, etc. Concepts are thought to be building blocks in terms of which the knowledge is represented (Lamberts and Shanks 1997). The terms used to describe objects embody some of the elementary technological concepts acquired by students through their everyday experiences. Only 3 students associated given artefacts with familiar natural or human-made objects, together giving 15 instances of associations. One student associated 5 objects (A, B...): A – tube light pillar, B – earthworm, C – Straw, H – toy supporter, I – tunnel.

Reasoning about Artefact Structure and Function

During the interview students had to describe the differences between their pre- and post-test drawings and justify changes, if any. Students did not show objects in propor-

Sr.No	Category level-1	Category level-2	Category level-3	Examples	Instances (tot=361)
1	Structure	Topology	Configuration, internal shape	Hollow, solid... arrangement of units	43
			Material	Iron, plastics...	84
			Property	Flexible, strong...	26
		Morphology	Gross shape	Rectangular, cuboid...	55
			Size(qualitative)	Long, short, big, small, thin, thick...	8
			Quantitative (Measurement)	Length, breadth...	50
2	Function			Tube used for transferring saline, pipeline connector...	30
3	Associations			Motorcycle chain looks like caterpillar	15
4	Concept terms			pipe	36
				rod	10
				tube	4 (tot =50)

Table 2. Instances of categories observed in students' descriptions in the intervention activity.

tion of their sizes. However, when the interviewer/researcher (R) drew their attention to given lengths and context, most students were willing to change their drawings as in the example below.

R=Researcher; S1=Student; []=Researcher comments

R: This is what you have drawn first and this is the second… This is a 100mm long solid metal cylinder. How did you decide this (pointing to the diameter) is 20 mm and this length is 100 mm?

S1: It should be... radius... radius is 10. This entire... is diameter. This is 20, this is diameter. I have shown radius.

R: Do you want to correct it?

S1: Yes

In the bicycle task, the students had the chance to make explicit their knowledge about bicycle parts and its working. Students were able to make structure-function linkages and reason about the working of bicycle in a conceptually modified arrangement as seen in the following excerpt.

R=Researcher; S6=Student; []=Researcher comments

R: There is a larger and smaller spiked wheel, what if we changed the position of the two spiked wheels? ... if we put the smaller one here and larger there?

S6: Harder we pedal, the speed of the cycle will go slower. Even if we pedal hard it won't go very fast. Like in the gear cycle...

R: Why would that happen?

S6: Because what we are moving here (points to smaller one) won't move that fast... see this is big... when we move [it] the more amount of chain goes here, so one rotation of this means 2, 3 rotations of the tyre. Whereas, if we make this [spiked wheels] opposite, two, three rotation of this [smaller one] will make one rotation of this.

R: Ok?

S6: So we need to pedal hard and still we won't go very fast.

Students were able to conceptualise the complex mechanisms involving structure-function relations and reason about movements of dynamic assemblies. Such reasoning shows students' ability to visualise components and dynamic relations (Hegarty, 2004).

Conclusions

This study probed students' understanding of artefacts using drawings and descriptions. The experimental design of the study involved four stages: pre-test, intervention, post-test and semi-structured interviews of students. The pre- and post-test had identical tasks, which required students to read, comprehend, interpret, visualize the textual description of objects and their assemblies and draw them.

The intervention exposed students to 10 objects of differing sizes, shapes and material properties. They had to fill a questionnaire with first estimated lengths of objects, then their measured lengths, and write a brief description of each object. Students tended to overestimate lengths smaller than 30 cm and under-estimate longer ones. The analysis of descriptions revealed that the structural features, especially topological, had primacy over functional and associative ones. The intervention included repairing a broken bicycle by repositioning the fallen chain back onto the spiked wheel and making it functional. In doing this, students explored the several parts and their functions in a bicycle chain assembly.

The post-test drawings of students indicated that intervention had little effect on the depiction of proportions of geometric objects. However, handling a bicycle led to a qualitative change in the parts depicted and the details drawn for the bicycle chain and pedal assembly task. This suggests that handling of objects contributes to student's understanding of details in the assembly of a complex, familiar artefact in real-world task. Drawing and personal interviews helped gain insights into students' procedural and conceptual knowledge about static and dynamic artefacts, and their reasoning about them. Drawing and handling of objects can mediate students' visualisation and reasoning about artefacts and help appreciate structure-function relations.

The study shows that prior experience of handling familiar artefacts helped students better visualize the components in an assembled artefact. Descriptions of objects in the abstract did not trigger the use of dimensions, even after an intervention activity that engaged students in handling and measuring similar objects. Thus, artefact and assembly visualizations are influenced more by the context of the task than mere familiarity or measuring and estimating skills. School learning experiences of visualization of objects can be enhanced if students are allowed to handle and explore objects as well as exposed to problems in authentic contexts. Such concrete experiences help students ground their learning and visualize their ideas of processes and systems in better ways.

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