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ABSTRACT

Presented are building activities, for elementary school children, using a variety of different materials. Weak materials, such as clay, straws and pins, paper tubes and index cards, are used as examples; structures built with these materials are displayed in photographs and discussed. Problems are suggested from which additional activities can be structured by teachers and/or students. Ways to extend building activities in the direction of large-scale construction are also described. (CS)

Teacher's Guide for

STRUCTURES

Elementary Science Study

Webster Division, McGraw-Hill Book Company

New York • St. Louis • San Francisco • Dallas • Düsseldorf

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The Structures Unit

Teacher's Guide for Structures

Related Units

Primary Balancing
Senior Balancing
Geo Blocks
Pattern Blocks

ISBN 07-017696-5

Preface

The Elementary Science Study is one of many curriculum development programs in the fields of science, social studies, and mathematics under preparation at Education Development Center, Inc. EDC (a private nonprofit organization, incorporating the Institute for Educational Innovation and Educational Services Incorporated) began in 1958 to develop new ideas and methods for improving the content and process of education.

ESS has been supported primarily by grants from the National Science Foundation. Development of materials for teaching science from kindergarten through eighth grade started on a small scale in 1960. The work of the project has since involved more than a hundred educators in the conception and design of its units of study. Among the staff have been scientists, engineers, mathematicians, and teachers experienced in working with students of all ages, from kindergarten through college.

Equipment, films, and printed materials are produced with the help of staff specialists, as well as of the film and photography studios, the design laboratory, and the production shops of EDC. At every stage of development, ideas and materials are taken into actual classrooms, where children help shape the form and content of each unit before it is released to schools everywhere.

Acknowledgments

STRUCTURES is a unit that has always seemed to have an inner force of its own. From the beginning, many people at the Elementary Science Study have worked on building things with children. Christopher R. Hale, Madison E. Judson, Anthony C. Kallet, Allan Leitman, Neil B. Mitchell, Phylis Morrison, and David Webster are among those who have contributed to the development of STRUCTURES.

Some teachers who helped in early teaching trials are Nancy Stone, Judith Rosner, Phyllis Cokin, and Jiffy Mott.

The Trial Teaching Edition of STRUCTURES was written by Allan Leitman, with the assistance of Ann Mellor and Adeline Naiman. The *Guide* has been revised in accordance with information received from the trial teachers. Mary S. Gillmor, Adeline Naiman, Emily Romney, and Nancy Weston have been especially helpful in the work of revision.

The photographs used here are those of George Cope, Joan Hamblin, Allan Leitman, and Major Morris.

Daniel H. Watt

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Introduction

From the first toe that dug in the ground and the human being that sensed the change . . . from each placing of one rock on another . . . from each pushing of mud into a new form—man has shaped materials to serve his needs and build his sense of mastery.

Young children can spend hours building on a beach or in a backyard, with water and sand, with earth, or with snow. When children build things in a classroom, this same absorption is evident. Children build in different ways and for different purposes. The particular focus which their work takes will depend upon what they are trying to do at any particular time. If they want to make models of actual objects, their main concern will be with representing

the objects to their satisfaction. If they are trying to build a useful structure, such as a cage, a workbench, a bridge, or a table, questions of utility will be more pressing than those of looks or simplicity of construction. Often children build with a combination of purposes. If you can determine *their* reasons for a particular type of construction, you will be in a better position to ask relevant questions and to offer appropriate suggestions and encouragement.

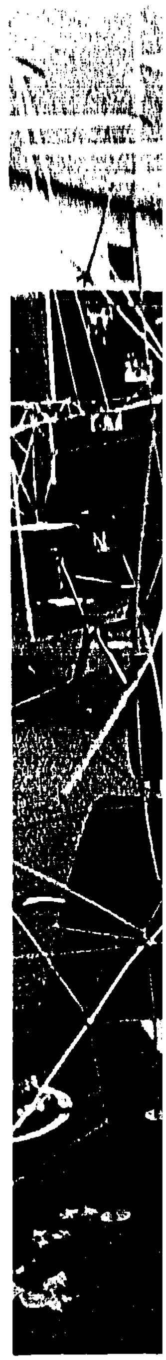
In any building activity, the material itself is one of the most important organizing factors. The physical and aesthetic properties of the materials being used will determine, to a great extent, how long, how tall, how strong, and how interesting a structure can be made. Wood, paper, clay, straws, cardboard, and spaghetti all present quite different challenges and opportunities. When children are encouraged to work freely on a building project, the materials themselves do much of the "teaching."

Most of the problems suggested in this *Guide* call for building with weak materials. They have been chosen because they present all kinds of problems in structural design. In their efforts to build with weak materials, children become interested in exploring the properties inherent in materials and the effect of different approaches to building. They often learn as much from their failures as from their successes. In reconstructing and revising a structure that has not lived up to his expectations, a child may try several different kinds of structural approaches before finding the one that best suits his needs. He will borrow freely from his classmates, accepting, rejecting, and modifying their ideas as he sees fit. It is in this way, rather than by sticking to a set plan or procedure, that a child is likely to get the most out of the type of building situation described in this *Guide*.

Using the Teacher's Guide

The activities described in the *Guide* should give you a feeling for some of the things that have happened in other classes, and ideas for the kinds of building problems that can be explored with common inexpensive materials. The suggested problems are intended as starting points, to provide an initial focus on some aspect of the materials at hand or on some building project. As their work progresses, your students will profit from being allowed to go in the directions that their explorations lead them or to begin new explorations of their own. Children who become involved in building will really create their own unit through activities that mean the most to them.

As a teacher preparing an environment for children, you should make available the materials and time that will support and extend the students' innate interest and capacity to build. Your challenge is not to organize and explain things about how structures work, but to help children to interact comfortably with one another and with the materials, so that they come to recognize the possi-



The questions and problems suggested in the *Guide* can be used in different ways. They may help to initiate work with one material or another. They may also be used to shift the focus of a building project in order to explore its possibilities further. For example, if a child has spent a good deal of time building towers, you might suggest that he try to build a bridge with the same material.

The questions in the *Guide* can sometimes be used as part of a group discussion, but they will usually be more effective if you question each child casually, as you move around the room talking to different children about their work. Suggestions for testing a structure may be given while work is in progress or after a child has completed a structure to his own satisfaction.

Occasionally it will happen that the entire class will be ready to move on to a new problem at the same time. More often, as children are working on their own, you will be able to make suggestions to individual children or small groups who are interested in something new, while the rest of the class continues with the problems they are working on.

Helping children to develop their own methods of analysis and trial-and-error techniques of problem solving is the main purpose of the STRUCTURES unit. In asking questions of the children or in making suggestions to them about their work, try not to shortcut their own attempts to work through a situation. Deciding exactly when and how to intervene is one of the most difficult parts of teaching this type of unit and requires that you observe the children carefully as they work—individually, in small groups, and as a class. It is when they seem to be bogged down or bored, on the one hand, or when they feel that they have completed a piece of work, on the other hand, that your interventions are likely to be most helpful.

Ages and Scheduling

STRUCTURES has been used with children from ages seven to twelve. You may want to approach it as a whole-class activity two or three times a week or to have smaller groups explore ideas and problems at various times while the rest of the class goes on with other things. As a whole-class study, the basic activities will take up to six weeks. If you go on to large-scale building, you may spend three to four weeks longer.

In any class, it is to be expected that some children will be very interested in STRUCTURES and will want to continue to build things for an extended length of time, while others will be ready much sooner to go on to another type of activity. Whenever possible, provision should be made for both kinds of involvement. One way to do this might be to set aside one part of the room where children could work on STRUCTURES during their free time or while other children are working on other things. In this way, those children who really get excited by building activities can gain the maximum benefit from their involvement.

Supplementary Activities

Many teachers have used various supplementary activities to extend their children's interest in STRUCTURES. Here are a few of them:

- Have available some books that deal with structures, building, architecture, and cities. Draw the attention of the children to these books while they are working on STRUCTURES. (On page 47 is a brief list of books that have been useful. There will probably be others in your school library or local public library.)

- Set up a bulletin board for pictures of structures that you and the children find interesting. The children can draw pictures of the structures they build or see. You can use these pictures as the basis for discussing the purposes of different structures and to help analyze the ways in which structures are built. Some children will enjoy trying to copy an actual structure from a picture.

- Arrange to visit an interesting local structure, such as a bridge or TV tower. This experience might inspire some children to try to copy the structure with their own materials. It could also serve very well as the focus for a discussion of the function of the structure or its construction, and the way the different parts contribute to the whole.

Materials

Children can use tables, their own desks, or the floor as workbenches. (If they need the space and your school permits it, you can use the hall.) It is helpful to have a variety of materials on hand. You probably have already (or can get from school supplies) such things as rubber bands, index cards, construction paper, newsprint, rulers, masking or cellophane tape, glue, books, scissors, and paper clips. Water, soil, and sticks should be easy to add. Below is listed a set of basic materials recommended for successful completion of the unit.

- 8 lbs oil-base modeling clay—reusable; this is enough for about half the class at a time (allow about ½ lb per student per project). Plasticine is recommended.
- 6 boxes plastic soda straws—reusable; enough for half the class at a time (allow about 100 per student per project)
- 500 straight pins (common pins)
- 3 spools thread
- 2 boxes toothpicks
- 75 ft copper wire
- 1 box paper clips
- 3 pkgs small washers
- 100 large washers
- 500 flat wooden stirrers (coffee stirrers)

The list below is included to give you an idea of additional materials that children have built with and that are easy to collect, buy, or borrow. All are good to have around, since they lend themselves well to building projects.

uncooked spaghetti

string

yarn

pipe cleaners

empty milk cartons

soap or cereal boxes

tin cans (be sure edges are smooth)

fast-drying glue (such as model-airplane glue or Duco Cement)

scraps of cloth

newspaper

sugar cubes

wooden blocks

Styrofoam blocks

stones

1" × 2" wooden strips (see pages 33, 35)

bolts and wing nuts (see pages 33, 35)

Tri-Wall cardboard (see page 32)

golf tubes (see page 31)

Tinker Toy

D-Stix

Construct-o-straws

other commercial construction sets

tools (for large-scale building; see pages 31–32)

If you do not already have one in your classroom, you will find a balance very useful.*

* *The Multi-Purpose Balance is available separately from McGraw-Hill. For further information about balancing in the classroom, see the Elementary Science Study units* PRIMARY BALANCING *and* SENIOR BALANCING. *These, like the balance, can be ordered from the Webster Division of McGraw-Hill Book Company, Manchester Road, Manchester, Missouri 63011.*

Building with Clay

Modeling clay is familiar to children and easy to work with. Since it has little structural strength, it is a material which lends itself well to the purposes of this unit. How can we build a structure which extends the usual limits of modeling clay? One way to start is to suggest that children try to see how large or how tall a structure they can build with a given amount of clay. (A half-pound or so is a good quantity with which to start.)

There is no "right" solution to such a problem, nor will any two solutions be the same. Children don't need formal rules in order to build with clay. Intuitively they balance . . . overcome forces . . . pull and push. As roofs fall in or towers bend, they will be finding out what is and is not possible.

As you walk around the room, you can help a child sustain his interest in a problem by measuring his structure with a yardstick, or by asking questions that will help him to try different approaches.

Where does it seem to be falling over?

Where do you need more clay?

What would happen if you gave it a little pull?

If part of a clay tower seems superfluous, you might pinch off that piece and ask the student how it could be used to make the tower higher.

At the end of 45 minutes or so, towers that began at six inches will have reached eighteen. In the course of modeling and remodeling their structures, children begin to think about what it is that makes things stand. A ladder that was meant to go up may have fallen over and become a bridge; a tower may have evolved into a tree.

Are trees and towers alike?

Making predictions about amounts of material is another problem that children enjoy.

If you had twice as much clay, could you make a tower twice as high?

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nuch clay.

Towers can go sideways and down, too. Part of the fun of building structures is finding a new vocabulary with which to describe new discoveries and problems. A class or group discussion might center around naming the clay shapes or mentioning familiar things that the shapes remind the children of—arches, spires, pyramids, and stalagmites.

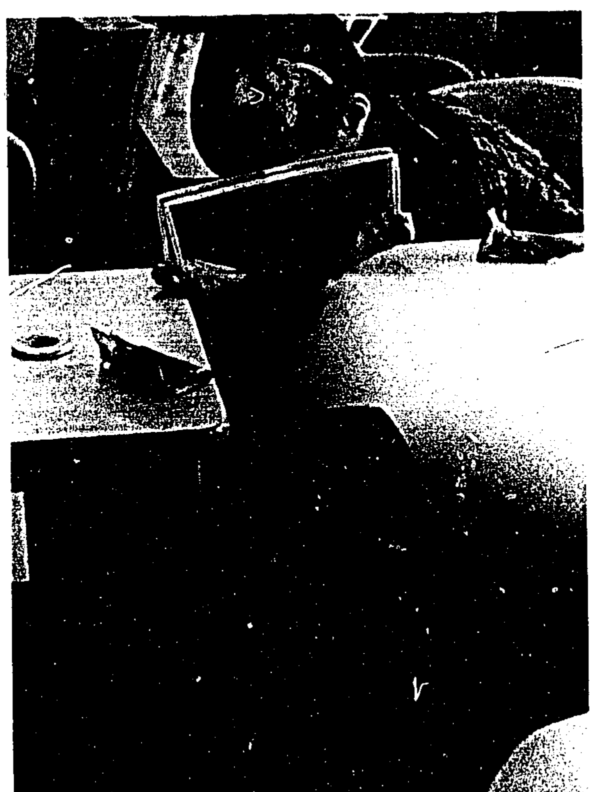
One possible way to sum up building with clay is to have a contest to see who can build farthest up, out, and down with a half-pound of clay. Have the class decide on a scoring system.

Do you get the same number of points for an inch going down as for one going up?

One class decided that it would be hardest to build an "out" structure from the side of the desk. They decided to award five points for each "out" inch. Using similar reasoning, they gave two points for every "up" inch and one point for every "down" inch. Within half an hour, the winners were up to 80 points or more.

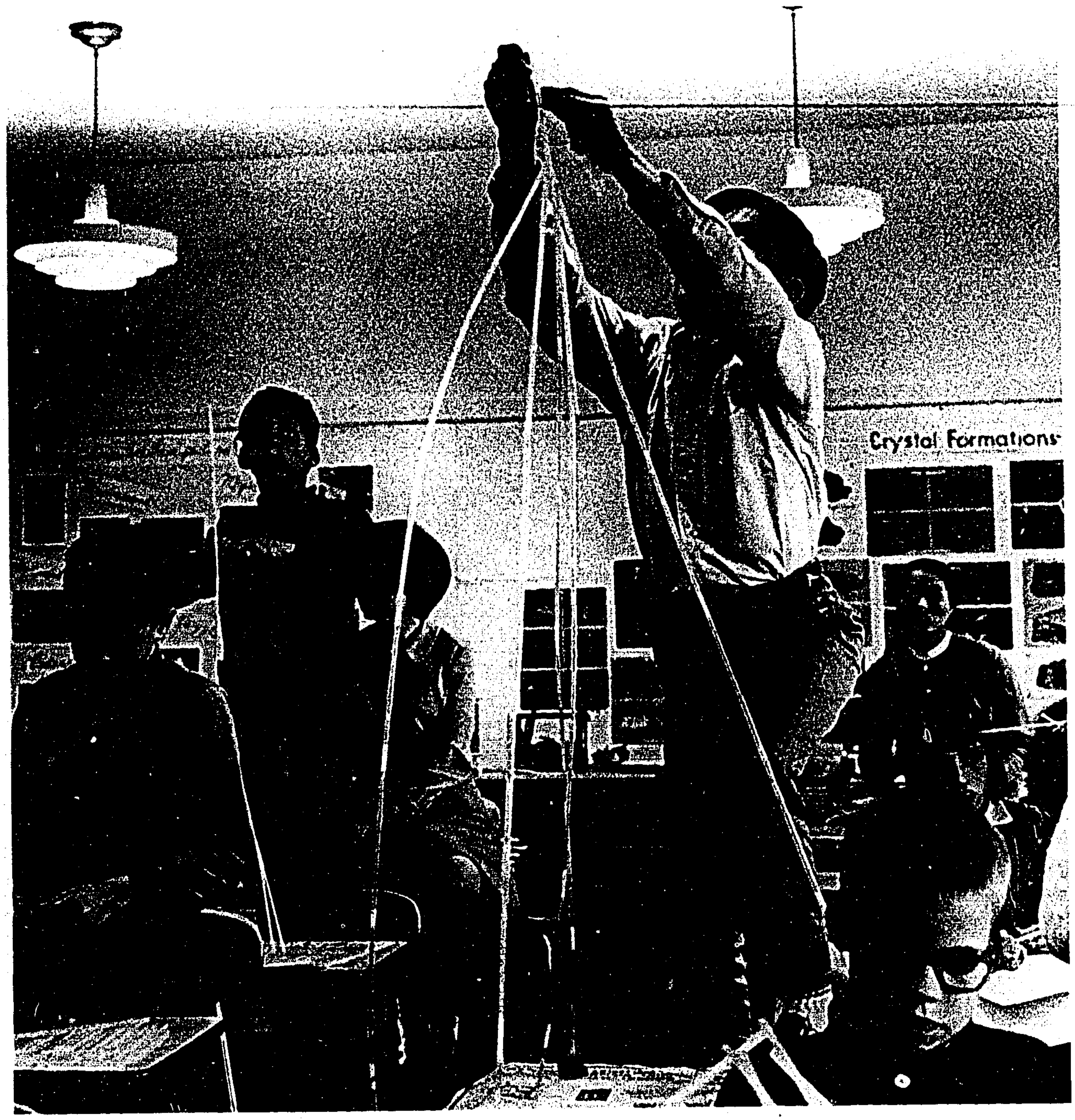
Clay Bridges

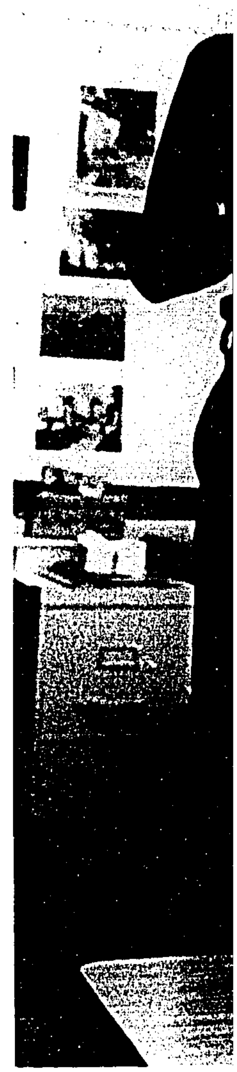
Some children may be interested in building bridges with modeling clay. In one class, the suggestion that children build bridges led them to roll long strips of Plasticine and suspend them between desks. The children wanted to see how long they could make their strips without breaking them. The teacher used the hanging strips as a focus for a class discussion of how the length and thickness of



Straws and Pins

How can you build with straws? You can fit them inside one another, or you can connect them with something.





Sometimes specific problems help to ext building with straws.

What is the highest structure you c and 50 pins?

Can you build a bridge from one des

Can you build a structure coming ou

A number of teachers have used problem a contest to see who could build the tall

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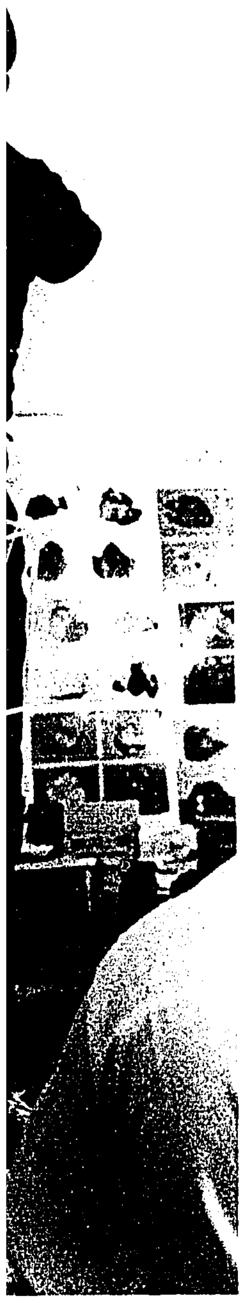

ildren bring in and post around the room ırces of new ideas for building projects. ·s or construction sites have also been a some children.

:ouraged to test the strength, stability, and ıres they build. In this way, they gain in- of structures that are subjected to outside e how to improve their structures so as to

·uctures. One way to test the st
ashers from the bridge, using o

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washers are hung?

e likely to collapse if the w
are all in one place?

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gthened so that another are

·e that one will be?

Questions like these can help the children see some of the implications of what they are doing when they test their structures.

In one fourth grade classroom, a group of students had constructed a number of elaborate straw structures. The teacher handed one boy a pair of scissors and challenged him to cut a straw in his structure that would not make the whole thing fall down. The boy looked at the interlocking straws for a minute and then gingerly cut one of them in half. The structure remained secure.

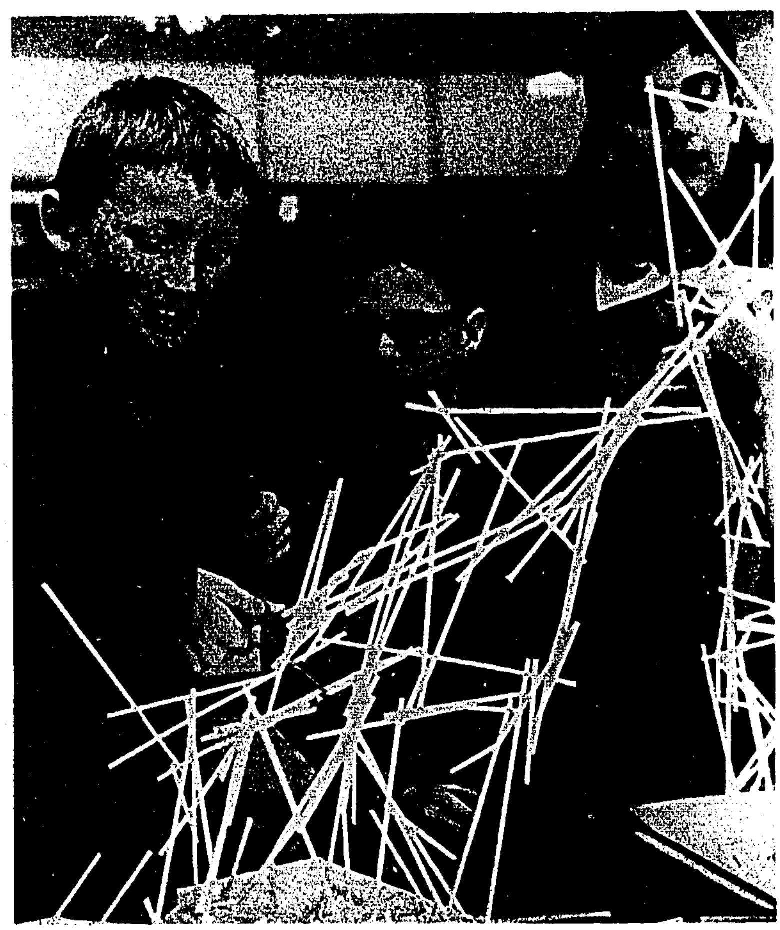
"How many times do you think you could do that before it would collapse?" asked the teacher. The rest of the straw builders had gathered around by this time. Everyone wanted to make a prediction—

"Three."

"None."

"Twenty."

The scissors w ere passed on to another student who made a second cut. Excitement and discussion grew as each successful cut was made, un' nally, on the fifteenth cut, the structure tottered and began to



One child, whose turn was to have been next, was sure that one more cut would have been possible. He propped the structure up again by taping the last straw together and cut the straw that he thought would have no effect. He was right—he had found one more possibility. The children agreed that fifteen was the limit for that particular structure and went on to another straw construction to predict and cut again. As they went along, their predictions became more and more accurate.

Build a structure that will need very few cuts.

Can you build something with twenty straws that won't take any cuts? . . . with thirty straws?

The stability of straw towers can be tested by means of a "wind test." Wave a large piece of cardboard back and forth next to the structure. If the tower doesn't fall over or bend excessively, it has passed the "wind test." If it falls, you can ask the children—

What could be done to make it stand up or prevent it from bending?

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Paper Tubes and Index Cards

Paper is another valuable material for experimentation and exploratory building.

How strong can you make a piece of ordinary writing paper?

How can it be rolled or folded to increase the load that it will support?

This has been an absorbing problem to children, and the results can be astonishing.

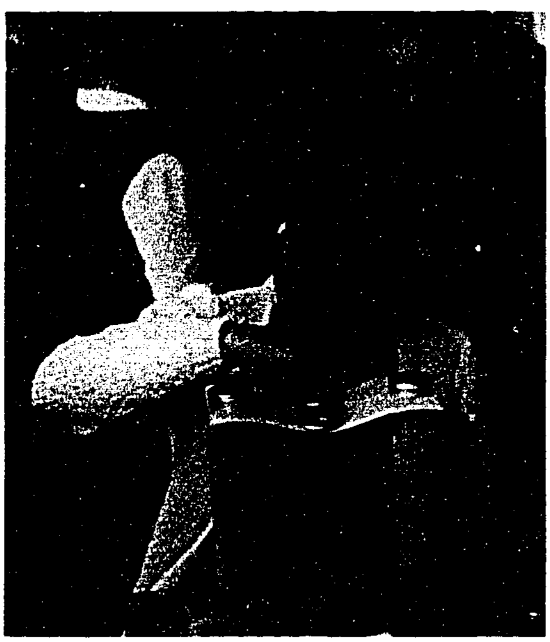
A good material for making child-sized structures is large sheets of paper rolled into tubes and held together with masking tape.

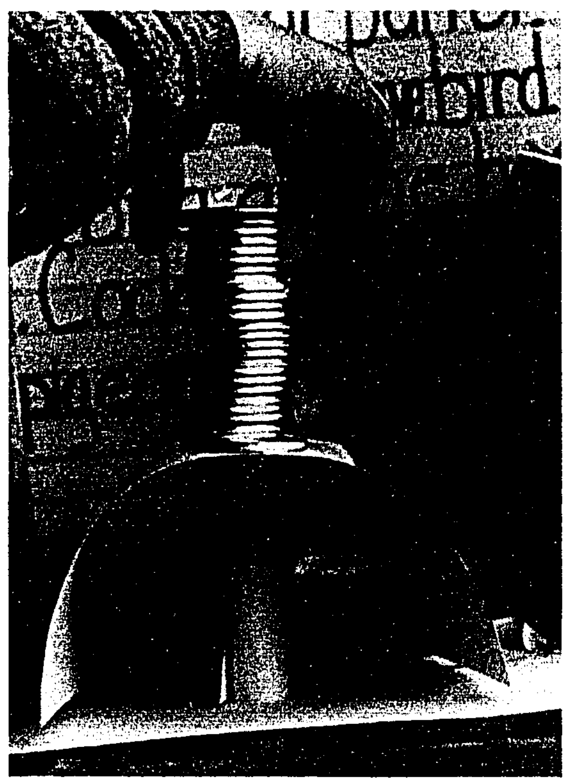
Try building bridges with index cards. Place an index card between two desks, and see how many pennies or washers it will hold.

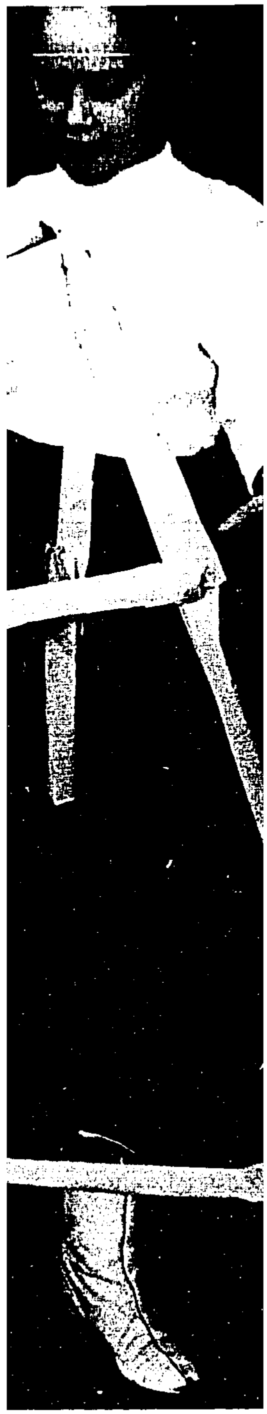
Is there any way to strengthen the bridge?

Would different ways of folding or rolling the card increase its strength?

This boy got his bridge to hold a lot of big washers. The class couldn't decide whether or not his solution was fair. Was it?



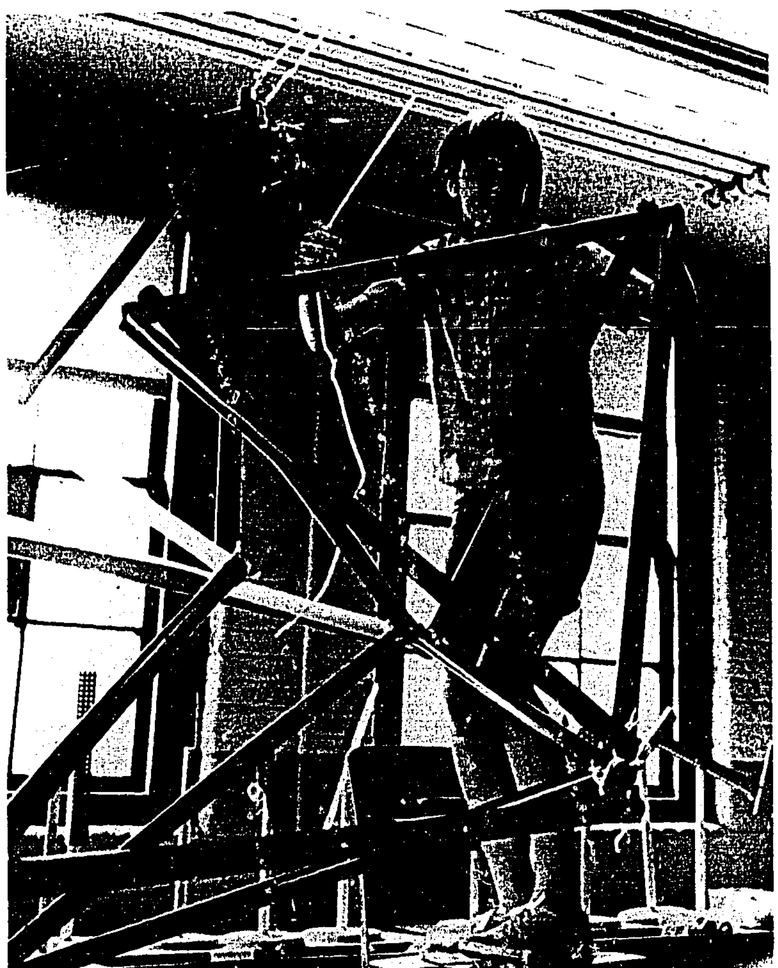




Large-scale Building

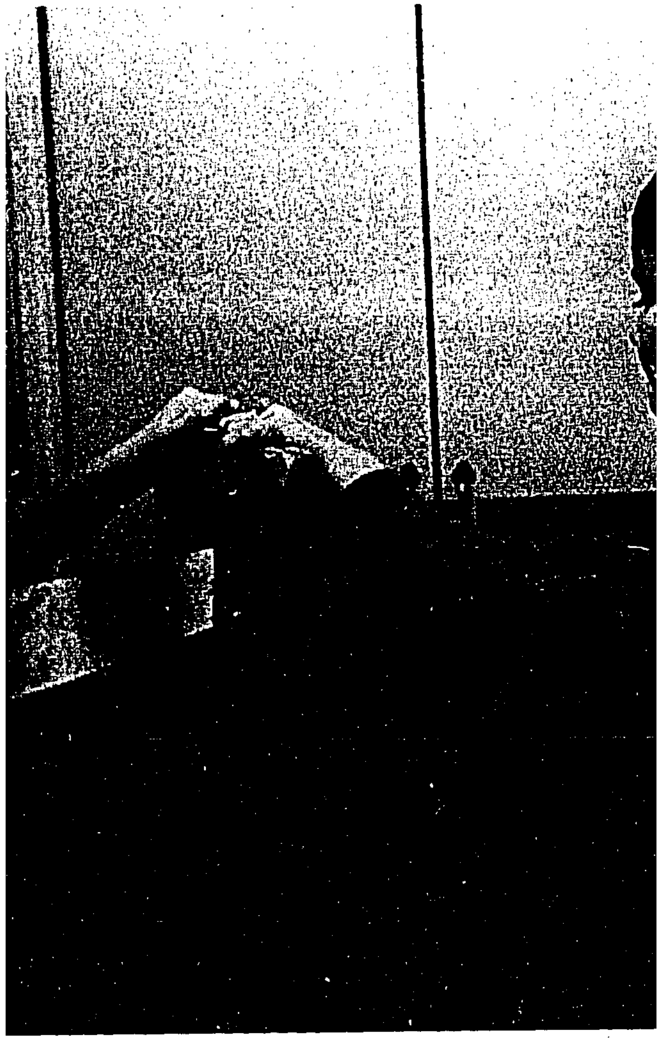
A number of teachers have requested information about how their children could extend their building activities in the direction of large-scale construction. The materials suggested below have been used successfully in a few classes but have not been tested extensively.

Golf tubes* are effective and inexpensive building materials. A paper-hole-punch will make holes in the ends of the plastic tubes, which can then be tied together with pipe cleaners or pieces of



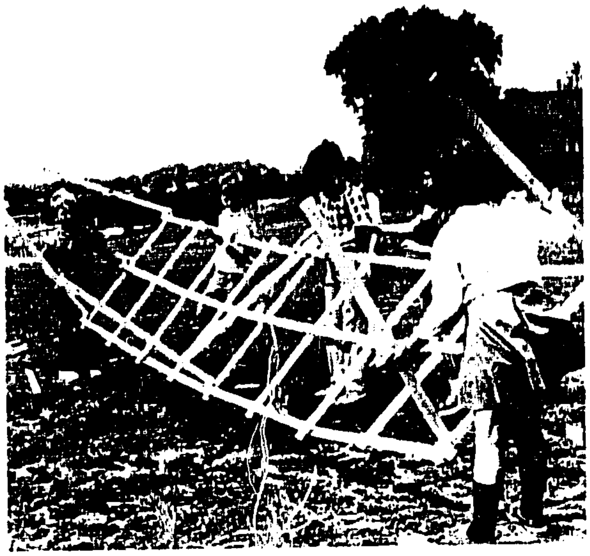
Golf tubes are plastic tubes about 34" long and 1¼" in diameter. They come in various colors and are sold in sporting-goods stores for the purpose of separating golf clubs within a carrying bag. Their retail price varies from 8¢ to 14¢ each. They are durable and reusable. A set of about 50 would probably be enough for a class to use for a year.

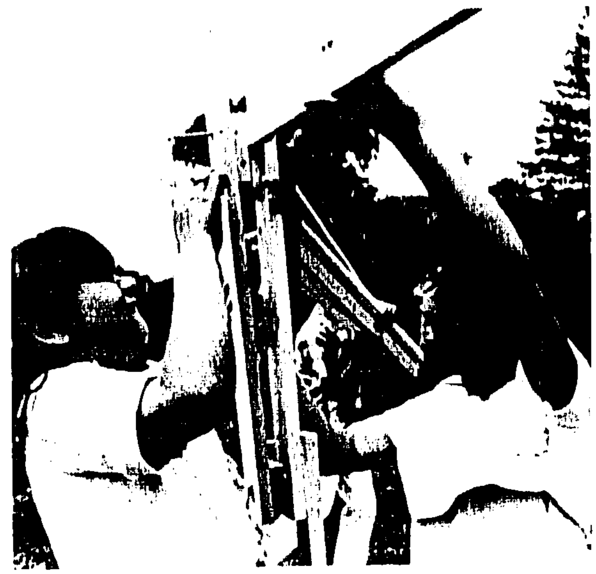
>s make impressively large and colorful geometric
ough these structures are not strong enough to carry
weight, their very weakness gives rise to problems
the ingenuity of the children building with them.



ıoard* is another material that lends itself to large-
tion. It is easily cut by older children, using either a
a handsaw, and it is strong enough, when properly
hold the weight of an adult or a child. The children
evelop their own methods for connecting and sup-
-Wall pieces.

*bought from the Tri-Wall Corporation, 1 Dupont Street, Plain-
d, New York 11803. If scraps of Tri-Wall are available in your
probably serve well in this kind of activity and will save buying
ıore information about Tri-Wall, see the booklets* Cardboard
oard Carpentry Workshops, *and* Cardboard Carpentry, Draw-
es. *All are available from the Workshop for Learning Things,
opment Center, Inc., 55 Chapel Street, Newton, Massachusetts*

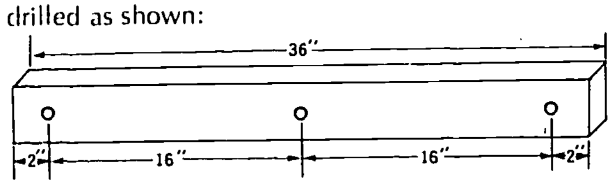




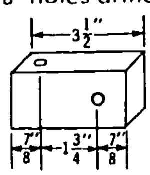
With a certain amount of carpentry, it is possible to construct a wooden building kit with which children can build life-size bridges strong enough to carry their own weight or the weight of a teacher. One kit can be used by five or six children at a time. Because of space limitations indoors, many teachers may want to wait until this activity can be carried on outside in warm weather. A group of children will probably need an entire morning or afternoon, and perhaps more time, in order to complete, test, and modify a large wooden bridge. There are many ways to get children started on such a building project. If there is a small stream near the school, bridging it could be the problem. A sidewalk near the school could provide a substitute for a real stream. One class was simply asked to build a bridge that was four sticks long and one stick wide. The final test was to be whether or not the bridge would support the weight of the teacher.

One such building kit can be made as follows:

40 1" × 2" wooden strips, 36" long, with 5/16" holes drilled as shown:



25 1" × 2" wooden strips, 3½" long, to be used as crosspieces, with 5/16" holes drilled as shown:



50 ¼" machine bolts, or carriage bolts, 4" long, with 50 wing nuts.

The wooden pieces are cut from 1" by can be purchased inexpensively at any kit can be made from one bundle of ten To make the kit, you will need a hand or drill with a $^{5}/_{16}$" bit. The carpentry can b cooperative parent. In some schools, it m school or junior high school students to m shop.

The cost of the wood is approximately $ the bolts and wing nuts will cost abo hundred at a hardware store.

Community Constru

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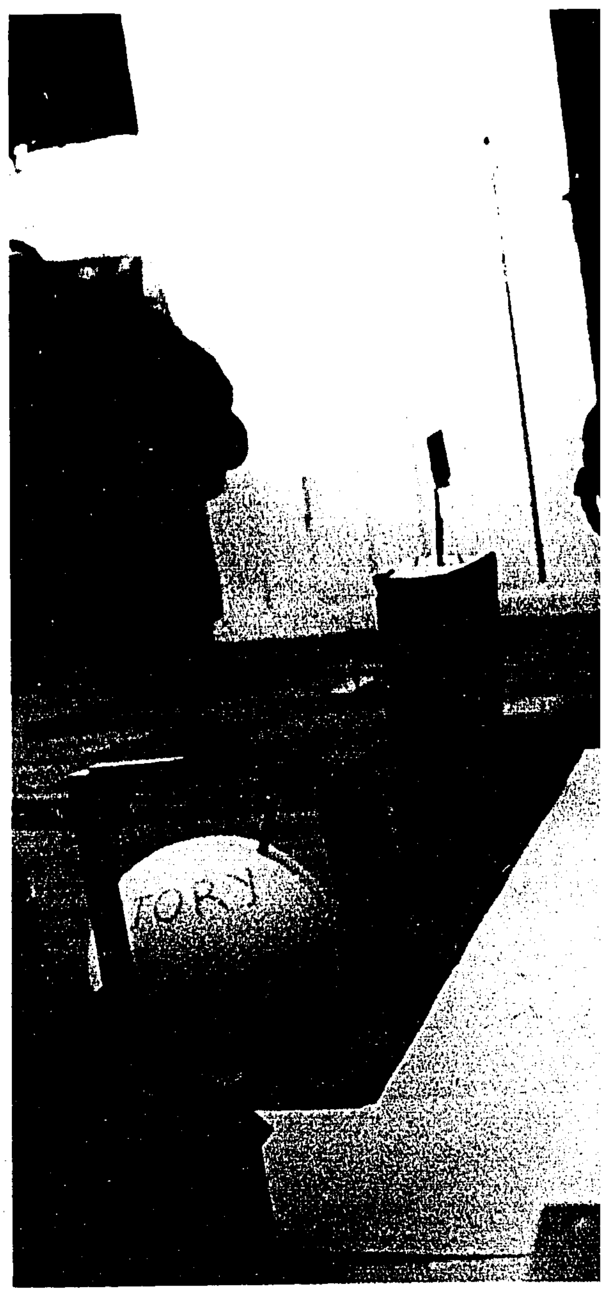

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›sent, past, real, or imaginary –
lems that will provide oppor-
› simultaneously.

Suppose a class becomes involved in building a modern city—

How big will the city be?

What will it be made of?

Where will the fire station be placed? . . . the police station? . . . the hospital? . . . the school?

What kind of transportation will be provided for the citizens?

How big will a person be if a 20-story building is three feet tall?

How will water get to the top of the tall buildings?

What should be done about garbage and sewage?

Can the city be lit with batteries and bulbs?

Can water be brought to the houses with tubing?

A project of this kind can be as involved as the class and the teacher wish it to become. It need not cover all aspects of city life, but some problems can be investigated in depth. Just finding the scale to use may take considerable time, and mapping the town after it is built is another profitable activity.

What materials can be used to build a 20-story building?

Can you use the same materials if you want to put things on and in the building?

Can you use the same materials if the model city is built outdoors?

What changes would you have to make in your building if you wanted to put it on display in the school yard?

Speech, art, reading, math, social studies, science, and crafts might all enter into such an undertaking.

A workbench is invaluable. With it, both you and your students will find opportunities for measuring, counting, drawing plans, shopping, scrounging, and making do.

Some children who bred mice in their classroom decided that the mice were bored by their cages. After making a trip to a dark corner of the school basement, they returned with an abandoned table-top, complete with its apron. It was like a shallow box. The children got the table to stand on edge, by cutting and nailing supports where needed. They spent a long time building different levels inside this basic cage, creating apartments, and developing a working elevator that the mice could use. This meant a lot of experimentation with pulleys. Finally, they fitted screening to the front of the upended table.

Taking care of the classroom and making repairs comfortably and naturally are also outcomes of having the tools available. Under these circumstances, children can carry out suggestions from books and can hold in their hands an object that existed only as words minutes before.

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To outfit a workbench, children need a hammer, a saw, a "C" clamp, and a surface to work on. Nails and wood scraps complete this minimum listing.

Here is a list of useful tools:

saw—it is worth buying a good one from a hardware store. Ask for a small cross-cut saw.

coping saw—for sawing curved lines in cardboard, as well as thin wood. The blades break occasionally, so keep a package of spare blades on hand.

"C" clamps—three or four 6-inch ones will do. Small clamps can't hold large things, while large ones can be closed down to hold small things.

vise—this is nice to have, but not absolutely necessary. Try getting along with the clamps for a while, and then decide if you need the vise. Some of the new kinds are easier for children to use than the old-fashioned ones.

hammers—at least one regular claw hammer. A 12- to 16-ounce one is heavy enough to help a small child sink a nail. It's helpful to have another type of hammer, such as a ball peen hammer, as well.

hand drill—drills and several different-sized bits are sold at most hardware and variety stores.

wood scraps—these can be obtained free of charge in almost any community—from lumberyards, carpenters' shops, construction projects, or factories which manufacture wooden products. It is best to have as many sizes, shapes, and kinds of wood as possible.

nails—several sizes. One kind children find easy to use is called a "lathing nail." It is about 1½" long and has a big head.

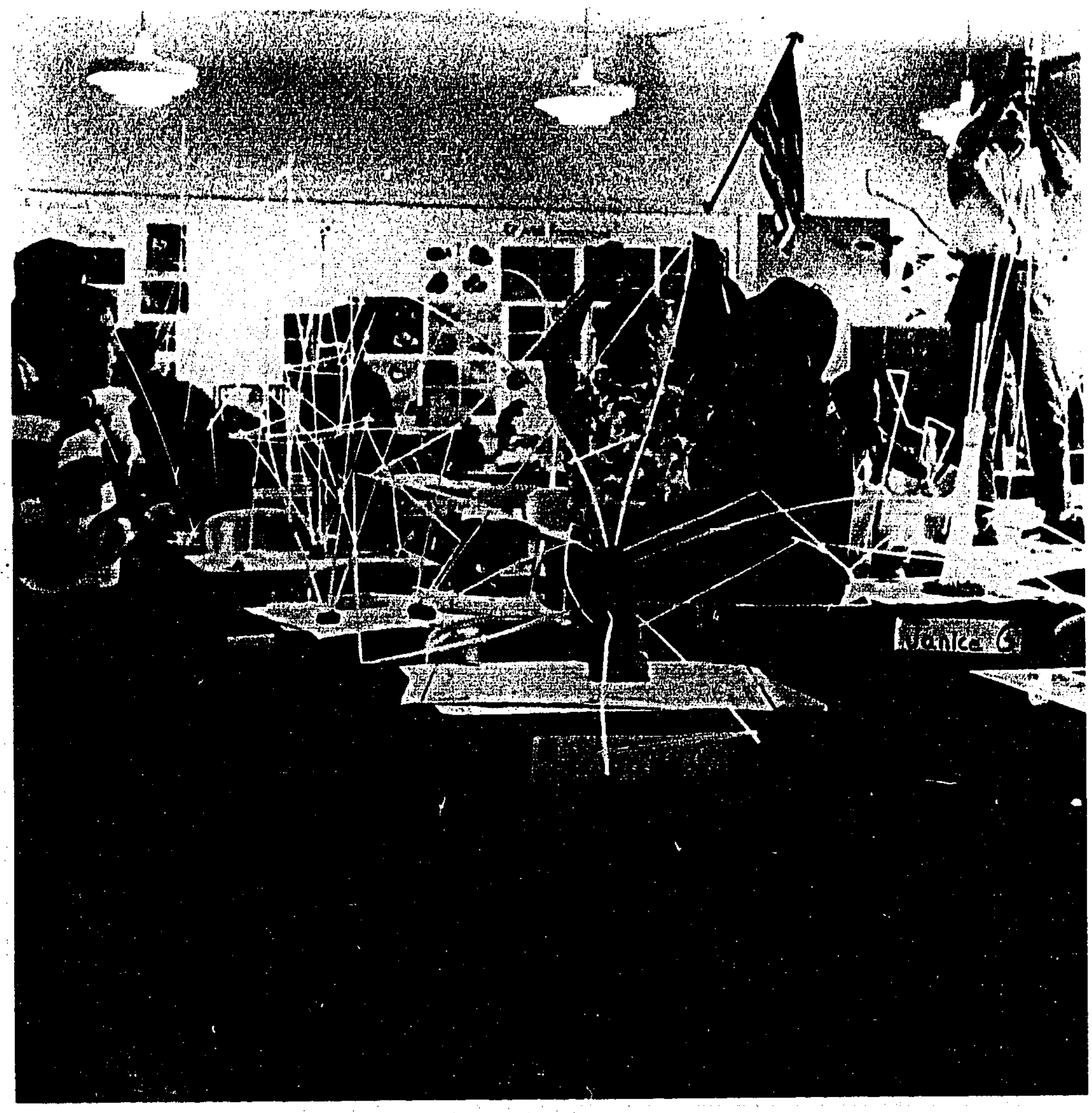
measuring tools—a foot rule, yardstick, long wind-up measuring tape, carpenter's T square for marking square corners. Introduce these measuring tools to your students gradually. Begin with one or two, and then add others as you feel the children are ready for them. Children come to a deeper understanding of the meaning of numbers when they have measured something because of a need.*

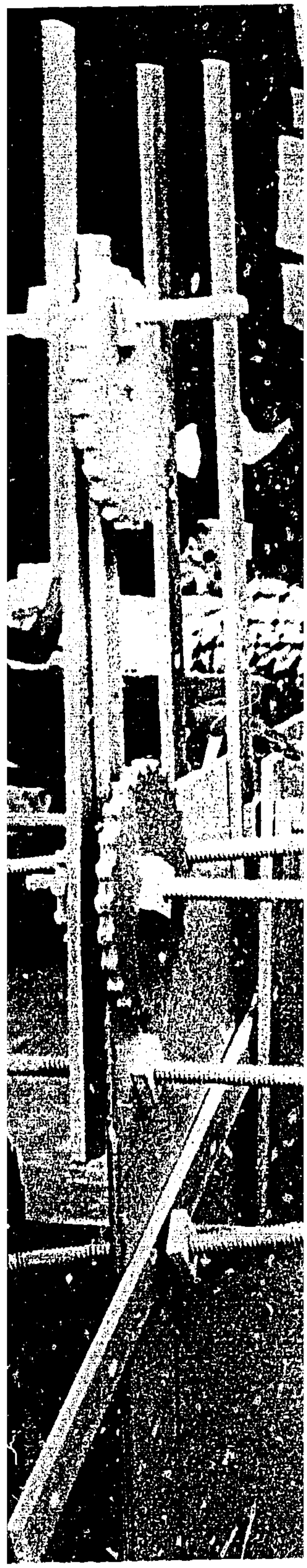
* *For more ideas about measuring activities which have worked well with children, see the Elementary Science Study unit* Match and Measure.

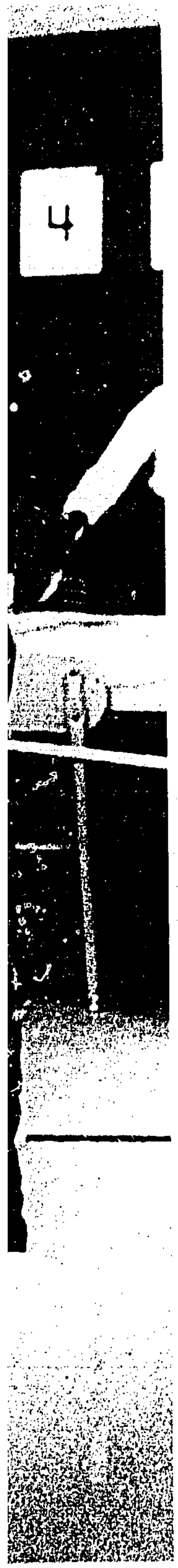
Commercial Construction Kits

There are a number of excellent commercial construction kits which allow the kind of exploratory building activities described in this unit. Here are a few of these kits which have been used in trial classes:

Tinker Toy, manufactured by A. G. Spaulding & Bros. Inc., Evanston, Illinois, is a well-known construction toy and need not be described here. It is particularly suitable for younger children, who can use it to explore problems involving shape, size, scale, balance, and stability.



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One of the most useful and versatile construction kits is *D-Stix*, manufactured by the Geodestix Company of Spokane, Washington, and available from Edmund Scientific Company, Barrington, New Jersey. A set of *D-Stix* consists of a large number of thin, wooden or plastic sticks of different sizes, to be joined by flexible plastic connectors. The different sizes are color coded, which makes them very useful for mathematical applications. Here are a few of the activities which can be pursued with *D-Stix*:

- *Building structures*: Present a problem, such as building a bridge or a TV tower, or, let the children build whatever they want.

- *Building three-dimensional geometric figures*: Children can try to copy certain kinds of geometric figures, or they can make up a rule for connecting pieces and see what kinds of geometric figures result. This kind of activity would lead to a lot of experience with geometric shapes and with the structural stability of such shapes.

- *Arithmetic activities*: Coming in specific color-coded lengths, *D-Stix* can be used for classification, ordering, sorting, and comparing. They can also be used for addition and subtraction, as well as for comparing ratios.

- *Investigations with plane geometry*: By making different kinds of plane figures in different sizes, children would gain some concrete experiences that could help prepare them for the more advanced concepts of plane geometry and trigonometry.

For large-scale construction, the Workshop for Learning Things, Education Development Center, 55 Chapel Street, Newton, Massachusetts 02160, produces a *Mechanical Building Set*. This is a sort of giant "Erector" set which children can use to build bridges, carts, derricks, pendulums, geometric shapes, and gear systems.

Suggested Reading

You may want to keep some books about building around the classroom, so that children can go to them for ideas and information.

The Whitman Publishing Company puts out a series of very inexpensive art books for children. Two of these—*Paper Art* and *Constructions*—offer a wide range of building ideas that children will find easy to understand.

The How and Why Wonder Book of Building, by Donald Barr (Grosset, no date) is a paperback that children in STRUCTURES classes have enjoyed.

Herman and Nina Schneider's *Science for Today and Tomorrow* (Heath, 1965) has a few pages that relate to building in the classroom. If you have this textbook, you may want to refer to pages 343–356.

Bridges and How They Are Built, by Daniel Goldwater (Scott, 1965) is an informative book for children about the construction of bridges, and offers many experiments that illustrate the points that it makes.

Here are three books on bridges that were written for adults. They contain many interesting pictures of structures that may help to stimulate children's interest in different ways of building.

High Steel, Hard Rock, and Deep Water—The Exciting World of Construction, by Richard W. O'Neill (Macmillan, 1965).

Bridges, by Henry Billings (Viking, 1956).

Bridges and Men, by Joseph Giles (Doubleday, 1963).

An excellent book for your own reference in this area is *Structures in Architecture*, by Mario Salvadori and Robert Heller (Prentice-Hall, 1963).

Origami (the Japanese art of paper-folding) is a fascinating related activity for children and adults alike. There are many books on the subject.