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Energy Efficient Architectural Design and Model Building

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This curriculum unit is designed for middle to high school level math-science teachers with two purposes in mind The first purpose is for math teachers who want to illustrate the principles of scaling, ratio, and proportion in a concrete way through model building. Too often math is taught in isolation, divorced from any ‘real life situations. This causes students much anxiety and frustration. Student’s failure to connect math with subjects outside the classroom leads them throughout their math program to see any relevance or application of the math principles they have learned. This unit counteracts the irrelevance of math. It teaches hands on skills that can be continually reapplied to changing conditions throughout a student’s educational career. The second purpose is intended for science teachers who want to teach practical energy efficient design principles, with particular emphasis on passive solar design.

Building a scale model house from cardboard has proven to be a very engaging activity that develops the skills of design and construction. It of also an excellent motivating factor in teaching basic math and science concepts to a large number of students. The final construction is exciting for both student and teacher. The student has the opportunity to physically and visually experience the process of creating a house, Just like an architect. All they have to do is follow the steps, 1) Preparing 2) Gathering Information 3) Designing 4) Constructing. (See the illustrations and student worksheets that are an integral part of this curriculum unit. They are available from the Yale-New Haven Teacher Institute office.)

The success of this unit depends on the ability of the teacher to be patient, flexible, and tolerant of student experimentation. The teacher must enjoy working with different types of material and the messiness involved in using these materials. The only prerequisite for the student is the ability to read a ruler.

This unit could be a course itself on architectural model building or incorporated into an existing basic math-science program. It could also be taught as an interdisciplinary unit on housing with a social studies teacher.

Major Concept, Subconcepts and Terminal Objective

Major Concept : Designing and constructing a scale model house uses critical analytical skills that apply the math principals of scaling, ratio and proportion and demonstrate the science concepts that relate to energy efficient building and alternative energy systems.

Subconcepts : I Scale drawings are similar to one view of an object. The scales give the ratio between corresponding parts of the drawing and the actual object. These corresponding ratios produce a proportion.

II. The application of science concepts that relate to energy efficient building design and alternative energy systems will be explored and evaluated.

III. Design and scale model house construction are processes that involve the collection of information, the evaluation of information, and decision-making based on that evaluation. Designing and constructing means constantly reevaluating your design and construction techniques as new ideas occur. The final product of constructing a model house involves all these processes and directly applies the ideas of scaling, ratio and proportion, and energy efficiency to a new, concrete situation.

Terminal Objective : Upon completion of this curriculum unit, students will be able to design their own floor plans (blueprints) and construct an energy-efficient scale model house from cardboard.

Instructions for Completing this Curriculum Unit

In the following two sections, each of the subconcept statements are presented individually. Each is divided into a statement of the subconcept, a performance objective, learning activities and a self-assessment activity. Read the subconcept and performance objective statements, do the learning activities as directed, and complete the self-assessment activity for each section before going on to the next subconcept section. When you have completed these two sections, in order, go on to the Final Assessment Activity and Quest sections.

I. *How to Interpret and Make Scale Drawings*

Designing your house will be easier, more thorough, and under control if you learn to make and use scale drawings.

Subconcept I: Scale drawings are similar to one view of an object. The scales give the ratio between corresponding parts of the drawing and the actual object. These corresponding ratios produce a proportion,

Performance Objective : Given a scale drawing of floor plan and the scale, the student is able to determine the actual dimensions of the lengths and widths. Also, when given the actual dimensions of the floor plan, the student is able to determine and draw the floor to different scales.

Learning Activities :

1) To the student: A picture is like a scale drawing. It shows the object as it looks, but it is usually

smaller or larger. The scale on a scale drawing gives you a ratio, It compares the lengths and widths on the drawing with the lengths and widths on the actual object. Give three examples when scales are used.
2) Complete worksheets 1 and 2 on proportional drawing. Hake sure they are correct before you go on to worksheets 3-11.
3) Measure this classroom, then draw three different floor plans of it on 1/4” graph paper, using the scales 1 Q =1’ (1/4’=1’), 2 Û =1’ (1/2 =1’), 4 Û =1’ (1 =1’)—Include all doors, windows, cabinets, and desks.
4) Draw a floor plan of your room at home, including all furniture. Draw the room again, this time doubling the scale.
5) Draw a floor plan of this entire floor in the school, DON’T DISTURB OTHER CLASSES!

Self Assessment : This consists of two parts: 1) a 75% score on the worksheets completed; 2) six completed floor plans to correct scale on graph paper. Consult your teacher before you proceed.

II *Energy Use in Homes: A Question of Design*

Residential use of energy accounts for 30% of the energy pie in New England. By thermally upgrading buildings and designing all new housing to be energy efficient, significant energy savings could be achieved, As it can be seen from the chart below, the big energy uses in the home are water heating and residential space heating, totaling 72.4%. This is an area where thoughtful design techniques can be essential in saving energy.

How You Use Energy

Pennsylvania State University says this is how energy is used at home;

Heating of space	57.5$
Water heating	14.9%
Refrigeration	6.0%
Cooking	5.5%
Air Conditioning	3.7%
Lighting	3.5%
Television	3.0%
Food freezer	1.9%
Clothes drying	1.7%
Others	2.3%

A Energy Use in Architecture

Yankee ingenuity worked to keep houses warm long before oil furnaces and electric baseboard heat was used. People’s lives were not oriented toward a thermostat, but revolved around the central fireplace used for cooking and heating, While the houses were drafty and cooler by present day standards, design elements were incorporated into many early buildings to minimize heat loss and maximize heat gain.

New England connected architecture allowed farmers access to their barns without having to shovel through snow, and ii the barn was connected directly to the house with no sheds in between, the body heat from the animals helped to provide a buffer of warmth against the cold. The saltbox style house allowed sunlight and heat to enter the more open south-facing front of the house while throwing a long, sloping roof into the coldest north winds. The center chimney cape allowed for ease in distributing heat, as did vents in second story floors. These architectural designs, in addition to location and different citing places, were a union of form and function that aimed to conserve heat.

The 1950's began a short-lived era of cheap and abundant fossil fuels. New houses were designed without regard to heat conservation, and consequently, when fossil fuel prices began to rise significantly in 1973, the percent of the family budget allowed to heating skyrocketed.

This dramatic price rise alerted designers and homeowners to the need for thermal efficiency in building design. It is interesting to note that as a result, many of the design elements of early American architecture have been revitalized. The south facing saltbox, the central chimney, and double airlock entry are a few energy-saving design concepts being revived.

Fuel use has influenced dwelling design since earliest people. With 72.4% of home energy used for water and residential space heating, it will be an influencing factor in the future. This figure could be significantly reduced by thermally upgrading existing houses and by designing new homes with energy consumption in mind. The era of cheap fossil fuels has passed, and architectural styles are evolving which reflect a need for thermally efficient buildings.

B. Solar Heat

There may be some confusion about the term solar heat. Solar heat can mean using ordinary building materials and techniques to maximize the extent to which a house is heated by the sun so that the load on the regular heating system will be reduced. This is *passive solar heat* , which will be the most practical approach for most people. The second kind of solar heat uses a complex system of rooftop collectors as the main heat supply. This is called an *active solar system* .

To heat a house with the sun's diffuse energy you must collect heat from a large area and concentrate it. In a typical active rooftop collector system an entire roof is oriented to face the sun and covered with a series of collectors. A collector is typically a box with a glass surface on the outside, an air cavity in the middle, and a black metal heat-absorbing surface on the inside. Like a greenhouse, the inside of the box heats up when the sun is up, even if the sky is overcast. The black inner surface maximizes this effect. Next to the metal surface is a network of pipes filled with water. The water heats up from contact with the hot black surface and is pumped to a heavily insulated storage tank. The large insulated mass of water is the heat storage mechanism. It stays warm up to a few days even when no fresh heat is coming in. (Sometimes the water mass will be combined with a masonry mass, which may be simply a tankful of rocks or a fireplace through which the water pipes flow.) The water from the colder portions of the tank is pumped up to the roof to continue the cycle. Another set of pipes reverses the collection process to heat the house. These pipes pick up the hottest water from the storage tank and circulate it to radiators distributed throughout the house.

In many systems the heat is circulated throughout the house by air instead of water by way of a system of air ducts much like the ductwork in a conventional forced air system, only larger in size. As in a conventional system, the air is forcibly circulated by a fan. A heat exchanger transfers the heat from the hot water to the air. This is essentially a coil or a network of small pipes something like a radiator, located inside the air ductwork, through which the hottest water circulates. The cool air blows across the coil or network of hot pipes, cooling the water and heating the air.

A solar collector system is at first glance tremendously attractive because it offers virtually free heat. In reality the first costs are huge, because your roof is covered with plumbing and plumbing is the most expensive part of any building. This is in addition to the cost of the storage system, the distribution system, the pumps, and installation.

C. Heating Efficiency

Though few can afford a rooftop collector system, anyone building a house can have an energy efficient house by applying a few basic heating principles thoroughly to their design. Taking pains with a hundred small details, each unimportant in itself, can result in saving about half the fue1 costs. These conscientious efforts are not just for economy's sake. An efficient house is more comfortable. Being sunny, bright, relatively uniform in temperature, and relatively free of drafts, your house will have a feeling of warmth even when the room temperature is low.

1. *Weather Orientation* , Your building site should be well open to the sky on the south, east, and west, because that's where the sun shines. The southern quadrant is particularly important, since the sun is there in the winter.

The house should be protected from winter winds (though not necessarily from summer breezes) by hills and plantings because the wind-chill factor cools a house just as much as it does a person. Outdoors .

The house must have sufficient window area especially to the south, to let heat in when the sun is up.

2. *Surface Area* , As important as how you heat your house is how to minimize heat loss. The heat loss of anything is proportional to its surface area. That is why radiators, which are designed to lose their heat, have fins or other irregularities to maximize their surface. In a house, you want to do the opposite, minimize the surface presented to the outside weather. The simpler the structure the more it will be heat-efficient. Many factors should influence the shape of your house. But a relatively compact shape will be easier to heat than a complex one.

3. *Insulation* . Most materials used to insulate buildings are efficient for the same reason down garments are warm. Both are fall of small cavities—dead air space—that trap air and interfere with the transfer of heat. The main idea is that heat loss is reduced by using more insulation. The effectiveness of any insulation is proportional to its thickness.

The most common and economical insulation is fiberglass. Until recently, the rule of thumb has been to use 3 inches in the walls and 6 inches in the roof and floor. Now many people are exceeding these amounts because fuel has become so expensive. For a cost of $500 for a medium-sized house you can permanently reduce your heating bill by approximately 15 percent.

4. *Window Placement and Insulation* . Windows lose heat about ten times as fast per square foot as do walls or roofs. Even a moderate window area can account for 40 percent of your total heat bill, One of the keys to

heating efficiency is to minimize this avenue of heat loss. You should eliminate inefficient window areas. You need south, east, and west windows for solar heat and light. You need north windows to see outside. But you do not need entire walls of glass. Your south, east, and west walls should have enough window for solar heat but not too much more. You should give a harder look to north windows, because these give no heat back even with the sun out. North windows should therefore usually be relatively few and small.

Next, use storm windows, insulated glass (Thermopane) or some other system of double glazing. This one step will cut the heat loss through the windows in half, which means an overall savings of around 15 percent. Even with double glazing, however, windows will still pour out heat at night or on overcast days when there is no compensating solar heat gain. Heavy curtains or, even better, insulated shutters can go a long way toward solving this problem. If you use a shuttering system well, you can save another 15% on your heat bill.

5. *Infiltration* , Infiltration means the actual flow of warm air out and cool air in. This leakage can be through small cracks in the siding, or around windows and doors, especially through cracks between the studs. It can also be simply from opening and closing doors. Infiltration can account for anywhere from 10 to about 40 percent of the total heat loss. There are several ways to keep infiltration down. Under the siding there should be some sort of continuous seal, such as plywood to keep the walls tight. Cracks around walls and windows should be caulked. Before you do finish-work you should stuff cracks with insulation. Weather stripping helps seal openings around doors and windows, A double door at an entry helps prevent large masses of cold air from coming in when people enter or leave. These precautions can save perhaps 15 percent of your total heat loss.

All of these percentages are of course approximate. What they amount to is that if you locate, design, and build your house with these features in mind, you can save tremendously on heating costs.

6. *Passive Solar Heat* . All these factors can be quantified, and there are engineering methods to compute them. When a house is engineered to maximize heating efficiency, the result is called passive solar heat A passive solar house may also include a simple system to store solar energy between sunny periods. Such a system will usually consist of a large masonry mass inside the house that is warmed up slowly by direct exposure to the sunlight. When the sun goes down, the masonry mass gradually emits heat into the surrounding room. Such a mass can be stone or concrete floor insulated underneath or a vertical mass such as an interior masonry wall or fireplace. One effective way to solar heat is to build a large stone or brick wall 4 or 5 feet inside a south wall with a large glass area.

Remember that solar efficiency, though valuable, is not your only design goal. Some people get so involved with making their house energy-efficient that they forget other equally important or more important needs. Most of the benefits of passive solar heat can be achieved by following sensible design practices. Space needs, or your own tastes should not be sacrificed for further, marginal reductions in heat loss.

Subconcept II: The application of science concepts that relate to energy efficient building design and alternative energy systems will be explored and evaluated.

Performance Objective : Students will integrate their knowledge about energy efficient and solar design principals into a proposed house design.

Learning Activities :

1) Provide students with magazines, pamphlets, advertisements, etc., which deal with alternative energy systems such as wood stoves and furnaces, solar collectors, wind mills, etc. Divide students into groups of 5 or 6 and have them make collages on poster board focusing on alternative energy.
2) Have students look through materials and identify terms which require definition clarification or concept exploration. These might include R values, specific heat, convection, B.T,U,, etc, With teacher assistance, have students research these terms and make a master list on newsprint or poster board that includes the term, meaning, use and example of usage, Leave list posted during unit. Discuss the terms listed as a class.
3) Supply students with sample house plans (Floor Plans are available in many magazines and books—see Bibliography). Select plans that represent four or five different architectural styles (ranch, saltbox, split level, contemporary, etc.). Have students select one of the designs and identity specific energy related aspects of their house plans (insulation materials, proposed heating source, window area, thermal mass, waste treatment). Once they have been identified, have students evaluate their design in terms of energy efficiency using science and math skills and knowledge gained in developing the master list of terms.
4) Construct the Model Solar House from your worksheets,
5) What solar concepts are included in this house? Which concepts are you going to use for your final house design? List 10.

III. Design and Scale Model Construction

How do you design a house? A common practice is to take an idea of a house seen in a book, in one's travels, or in one's mind eye, and just put that house on the site chosen. Another way that is different, more original, and may be better suited for you is to take the information you have about your land, your needs, and your budget, and develop a house design from that.

Begin by listing your design goals and experimenting with the items on your lists. First consider the qualities you might want your house to have: lots of privacy, skylights, a lot of sun, one or two stories, good views, high or low ceilings, fireplace, etc. Your next list should be more specific and include the actual areas you want your house to contain. This should generally not be a list of rooms, but of activities: eating, sitting, studying, reading, woodworking, wood storage, greenhouse, washing, sewing, car shelter, fixing a car, cooking, storing food, playing games, playing loud music, being alone, storage, etc. Include everything. This is not the time to be realistic. Activities can be eliminated later if necessary.

Write each activity on small, separate pieces of paper, Shuffle them around in different patterns to see which can be combined. Which functions can occupy the same or nearby space? Which must be isolated? Maybe you will discover old combinations that make more sense for you than the usual living room, dining room, kitchen, bedroom, bath arrangement. If you need both very quiet and very noisy places, you might be better off with two separate structures. You may want to save money by combining functions: eat-sit-visit or workshop-woodshed-noisy games, or greenhouse-bathroom.

Once you have developed your goals and priorities, it is time to make a scale drawing. But, making drawings is not just a way to put ideas on paper. It’s a way to develop ideas and make them work for you. Basically, you make a scale drawing, such as a floor plan, and then systematically ask yourself questions about it. Is the sun orientation good? Does the layout give enough privacy? Then you revise the drawing—changing dimensions, moving rooms around, moving doors and windows—trying to solve some of the problems. You revise the second version in the same way. This process continues until you have solved as many of the problems as possible, though compromise will always be necessary. When you have finished, your space will be efficient, privacy and communication will be good, etc. If your house has one or two rooms, this drawing process may be quick and easy. But ii your house is larger, making a drawing will be a major project. The more time you spend drawing and designing, the more the house will reflect your needs and be energy efficient.

Remember, your first design will be full of defects, which is to be expected. Revise it until you have a layout that really makes sense. Later you will make a more detailed plan that will include windows, doors, and the contents of the house.

Subconcept III : Design and construction are processes that involve the collecting of information, the evaluation of information, and decision-making based on that evaluation. Designing and constructing means constantly reevaluating your design and constructing techniques as new ideas occur. The final product of constructing a model involves all these processes and directly applies the ideas of scaling, ratio and proportion to a new, concrete situation.

Performance Objective : Students will design and draw floor plans of their chosen house, using passive solar design and energy efficient principals. They will then construct a scale model house from cardboard on top of the final floor plans.

Learning Activities :

l) Complete the worksheet design with a purpose. Have your teacher correct it before you go on to the next activity.
2) Look at the housing styles worksheet. Choose a style that you like best. List five reasons why you like this style. Which housing style is the most energy-efficient? Why?
3) Complete worksheets 1-7.
4) (Optional Activity) Using the isometric dot paper grid master which is included with the student worksheets, draw a two-point perspective drawing. It is difficult at first, but follow the instructions carefully. Don’t get scared’ A two-point perspective drawing is a house drawing from the same angle as the drawings on the housing styles worksheets.
5) Draw a front, side, and back sketch of your newly designed house.
6) On 1/4 graph paper, sketch the floor plan for this house,
7) Make a final floor plan to perfect scale for the house you will construct.
8) Build your cardboard model on top of your final floor plan. Materials needed: cardboard or mat board, rulers, rubber cement or Elmer’s glue, graph paper, paper cutter, scissors, and X-Acto knives.
9) Have students present their final design and house construction in class, explaining their choices of design and alternative systems. They should be able to use scientific data to support their choices and discuss the personal considerations that influenced their choices.

Self and Final Assessment : If your model is completed and to the correct scale as determined by your teacher, you are finished. Put the final touches to the model (landscaping). Congratulations !!!

Quest

This section will give you additional activities to extend your mastery of scaling, energy efficiency, and architectural principles.

1) Take photographs or make drawings of older houses in your neighborhood for an album; talk to the owner and collect information regarding the house—its style, date, location and changes made to the house,
2) Look through magazines and find a photo of each basic house style. Mount the pictures on illustration board for display.
3) Visit a contractor or architectural firm and ask for prints of the basic house styles. Bring these to class and discuss the advantages and disadvantages of each in respect to the families of different members of the class.
4) Using the New Haven papers, read through the “houses for sale section and make a list of the styles advertised. See if there seems to be a trend toward a particular basic style.
5) Redesign any space or object that you want to see changed.
6) Draw a scale model of anything that interests you.
7) Study the architecture in your town. Have students design an evaluation form to be used for analyzing buildings. Questions that might be included: What direction is the house facing? How many windows are on the north side? South side? Does the land scaping help to minimize heat loss? Is there an “airlock” entryway? Does the roof shed winds? What type of heat source originally kept the house warm? Compile data and discuss factors influencing architecture,
8) Have students prepare a slide show on the buildings they study. The energy conserving features and energy wasting features should be highlighted.
9) Have students do a survey of the public buildings in town. They should find out how they are heated, and how much lt. costs annually to heat them. Discuss what could be done to lower these heating costs, and invite town officers to the class to talk about potential energy savings.

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