An Engineering Design Curriculum for the Elementary Grades

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ABSTRACT

The United States has historically excelled in the design of products, processes and new technologies. Capitalizing on this historical strength to teach applied mathematics and science has many positive implications on education. First, engineering design can be used as a vehicle for addressing deficiencies in mathematics and science education. Second, as achievement in mathematics and science is enhanced, a greater number of students at an earlier age will be exposed to technical career opportunities. Third, enhancing elementary and secondary curricula with engineering design can attract underrepresented populations, such as minorities and females, to engineering as a profession. This paper describes a new and innovative engineering design curriculum, under development in the Austin Independent School District (AISD) in Austin, TX. The philosophic goals upon which the curriculum is based include: integrating the design problem-solving process into elementary schools, demonstrating the relationship of technical concepts to daily life, availing teachers with instructional strategies for teaching applied (as opposed to purely theoretical) science and mathematics, and teaching teamwork skills that are so greatly needed in industry and everyday life. Based on these goals, kindergarten, first grade, and second grade engineering design lessons have been piloted in AISD, in conjunction with a University of Texas program for teacher enhancement and preparation.

I. INTRODUCTION

The United States has historically excelled in the design of products, processes, and new technologies. In particular, achievement in engineering design has been a notable aspect of many of the U.S. Fortune 500 companies, including the development of the automobile by Henry Ford, the first commercial business computer by IBM, and success in the aerospace industry by such companies as Hughes Aircraft. Our historical national strength and interest in engineering design can be used as a vehicle for mathematics and science education. First, while engineering design has been considered a noble profession, it has been saturated by white males, not a representative cross-section of our population in terms of females and minorities. The elementary and secondary curricula of our nation needs to be targeted and enhanced in engineering to attract these underrepresented groups to engineering. Second, it is common knowledge that today's American students have deficiencies in math and science achievement, especially compared to other developed countries[1]. Appropriate curricula in engineering design can be used to address these deficiencies by providing supplementary instruction in applied mathematics and science. Third, with an increased educational focus on design, a greater number of students at an earlier age will be exposed to technical career opportunities, resulting in a potential increase in the pool of engineering and science specialists in our society. In this paper, we describe a new and innovative design technology and engineering curriculum (DTEACH - Design Technology and Engineering for America's Children) that addresses these three areas. Both materials development and teacher training are discussed with respect to this curriculum. The following sections specifically define the global context of the project, our meaning of engineering design and design technology, the grade levels that are being targeted for this curriculum, and the ultimate goals and objectives of the program.

A. Definition of Engineering Design and Design Technology

The term "design technology" is generally used to describe curricula that vary from arts and crafts to industrial technology to engineering. In the United Kingdom[2], the design and technology curriculum includes a focus on design as a process, a strong tie with industry, and a rather clear distinction from the science curriculum by emphasizing design as industrial art, not engineering. Programs in the United States are starting to develop their own characteristics for an early design curriculum; however, very few U.S. publications specifically address the concept of Design Technology for elementary grades. In fact, no curricula with sequential *engineering activities* in design technology currently appear in catalogs in the U.S. The discussion in Section 2 below will detail some similar programs that are in place.

In our approach, engineering design and design technology is an interdisciplinary curriculum that gives students in grades K-6 experience in *engineering* concepts and devices such as levers, wheels, axles, cams, pulleys, gears, forms of energy to create motion, etc. The interdisciplinary nature of design technology emerges within the context of children's projects, in which students solve design problems by creating and building models that illustrate what the students have learned from science and mathematics, in addition to literature and social studies, and use engineering process skills such as teamwork, design methodology, trial and error, and qualitative evaluation. Skills are presented developmentally: the youngest children work on the simplest design skills in mechanical applications, while older children increase these skills, experiencing applications in different engineering disciplines.

B. Program Goals and Objectives

The philosophic goals which drive the development of a design technology curriculum include the following: (1) integrating the design problem-solving process into the elementary schools; (2) demonstrating the relationship of technical concepts to daily life; (3) availing teachers with instructional strategies for teaching applied (as opposed to purely theoretical) science and mathematics; (4) teaching teamwork skills required of industrial employees; (5) providing opportunities for high-level thinking and critical thinking in science and mathematics; (6) giving students opportunities to use intuitive mathematics as a basis for concept development; (7) providing a milieu within our school curriculum for young "gifted tinkerers"; (8) and providing their teachers with a forum for identifying such students. The immediate arena for achieving these goals is within the Austin Independent School District, although plans are in place to disseminate the curriculum at the state and national level. The rationale for these philosophic goals is presented in the next section in the context of a historical perspective of design technology education.

II. History and Rationale for Design Technology

A. Other Design Technology Programs

Design Technology started as a curriculum movement in the United Kingdom during the early 1980's. Initially integrated within a Craft, Design and Technology (CDT) framework, the outcomes of the activities in terms of student involvement with materials and awareness of industrial processes led to a "Design and Technology" pre-college component of the National Curriculum in technology by 1989[2]. Early in the curriculum, students are assessed on their ability to recognize problems and generate problem statements. Older students work on design problems using fabrication and aesthetic criteria as well as functional criteria. This emphasis on non-scientific approaches may be a by-product of the separation of the science and technology curricula. This separation is also evident in the U.S. In contrast, the DTEACH approach integrates science and technology by emphasizing them equally.

1) Technology Education Projects: Technology education varies widely in U.S. schools. At one extreme is the Austin ISD, where the current status of technology education is to develop computer literacy or familiarity with machines such as laser disc players. At the other end of the spectrum is the Technology/Science/Math Integration Project of Mark Sanders at Virginia Polytechnic Institute for middle school activities. This project provides "design under constraint" activities similar to design technology activities. At the elementary level, Bill Duggar, of the same institution, heads up a "Mission 21" project, funded by NASA, which has resulted in a curriculum published by Delmar[3]. This project, while including design activities and current technology, only considers a specialized component of the technology spectrum.

Other science and mathematics curriculum improvement efforts include integrated math-science projects at the elementary level. For example, AIMS (Activities to Integrate Math and Science) provides teachers with in-service training and workbooks with student data sheets for performing investigations and recording data on charts[4]. Activities such as these can be said to integrate math and science, but long-term development of in-depth concepts and scientific thinking may not necessarily be addressed, due to the lack of experiences with actual technology from everyday life.

Physical science instruction is generally lacking in the elementary grades, particularly as indicated by currently available published curricula. The Operation Physics project of the American Institute of Physics provides hands-on training for teachers in physical science around the country. During the training sessions, teachers are given opportunities to examine the interrelated nature of physics topics. In contrast, the DTEACH curriculum presents physical science concepts through applied projects such as in "design-under-constraint" schemes. Rather than the teacher defining what is to be learned, the children define the information they need during construction of prototypes.

Other programs in the United States focus on increasing the mathematics and science skills of elementary students. One notable example is the Society of Automotive Engineers program for grades 4-6, "A World in Motion"[5]. The primary vehicle of learning in this program is observation of a number of experiments, with a very small portion of the program devoted to a single design problem and teamwork. Programs like "A World in Motion" are useful in providing hands-on science experiences for upper-level elementary students. However, the DTEACH program provides a more enriched environment, emphasizing not only physical sciences, but also engineering design as a process. The DTEACH program also extends such curricula to the primary grades, kindergarten through third, which have largely been ignored.

2) Summary of Related Work: This brief review provides a basis for comparison of the DTEACH project to the current programs and publications. While design technology has been recognized as an important educational subject area for K-12, and while preliminary materials in the form of general sourcebooks are available (*e.g.*,[6]), *no "teacher-ready" curriculum has been developed, tested, or published for the primary elementary grades*. The DTEACH project addresses this need, through a curriculum that integrates engineering concepts, basic technology, and teacher training and preparation in engineering fundamentals.

B. Rationale for DTEACH

DTEACH is a curriculum which differs substantially from those discussed above. The DTEACH project challenges students at an early age to use higher-level thinking skills during manipulative exercises and constructions. For example, kindergarten students are asked to predict the shape a cereal box will take when flattened out, and then use the principles learned in an open-ended design problem. At grade 2, black-box modeling is introduced as a strategy for thinking about systems and processes during design. This skill is then related to other science inference activities, such as math "function machines", in which algebraic relationships are illustrated with simple mechanical devices, and to cause-effect activities in reading, in which students identify the reasons that events occur in stories that they read. Open-ended, developmentally appropriate activities, such as the *engineering design-under-constraint* activities of DTEACH encourage creativity during science activities.

As stated in the goals, the DTEACH project includes an in-service teacher education component that addresses deficiencies suggested by the results of elementary school teacher surveys. A quiz composed of selected items from a fifth/sixth grade aptitude test was given to kindergarten and first grade teachers who were beginning to teach the DTEACH curriculum. The results of this particular quiz show deficiencies in geometric and spatial reasoning. Additionally, the great majority of elementary teachers in Texas have not been trained in engineering, and typically have taken few science courses in college[7]. Through the DTEACH program, teachers are trained to a level of expertise that will enable them to formulate design problems.

Another deficiency that the curriculum addresses is science achievement and participation differences between boys and girls, differences which appear both at home and at school. Boys' parents encourage development in mathematics and science, on average, especially through math and science-related toys[8]. It has been shown that children who play with construction toys and handle tools develop better spatial abilities and scientific aptitude[9–11]. The largest gender "gap" in this area occurs in out-of-school activity time with "tinkering" activities, in which girls' participation is very limited[12]. DTEACH activities provide spatial and mechanical opportunities for girls, missing not only from school science but also from home experiences.

III. Educational Program

A. Description of the Pilot DTEACH Curriculum

To demonstrate the initial feasibility of a Design Technology curriculum, a pilot program with preliminary lessons has been implemented for the kindergarten and first grade levels. This preliminary curriculum is in the form of les-

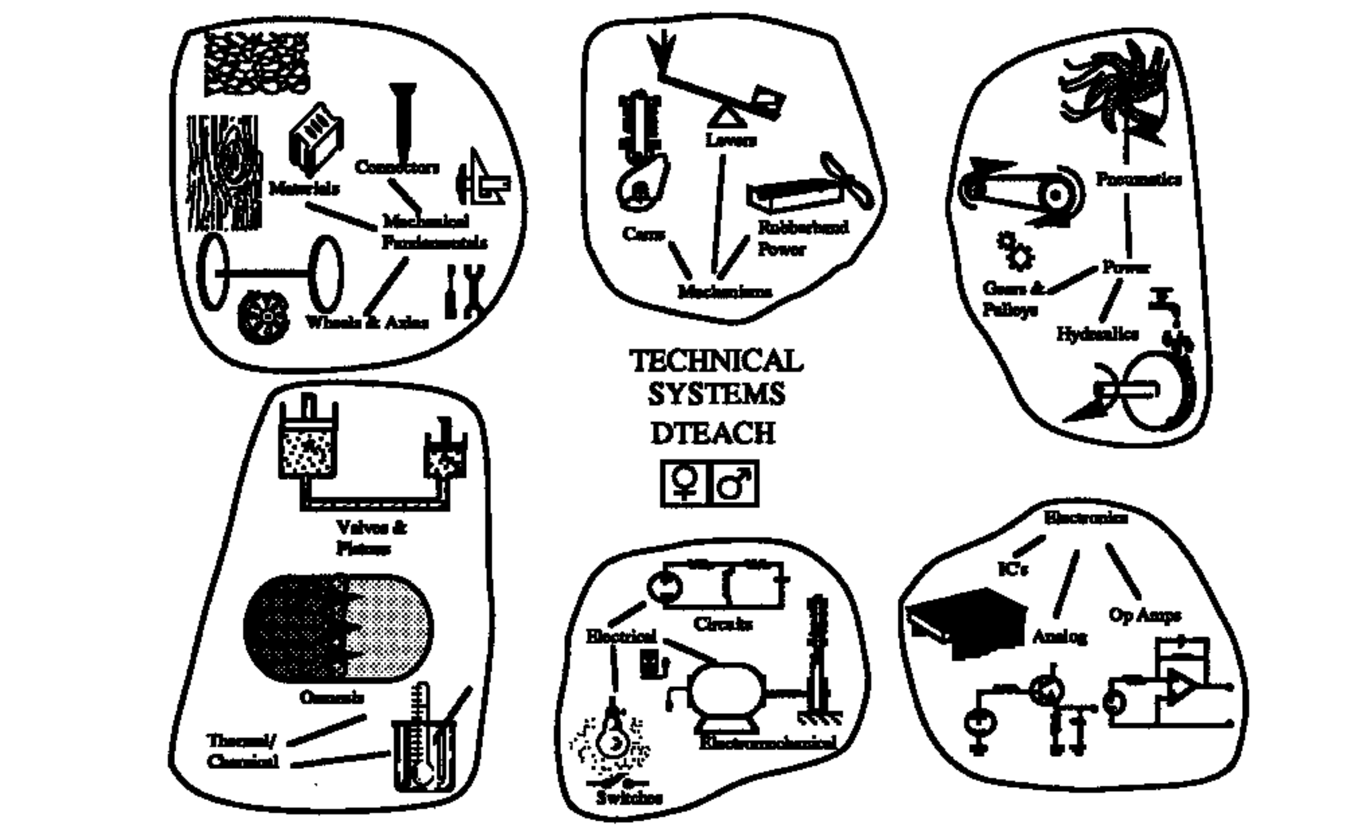

Figure 1. Example DTEACH technical concepts.

son “units” taught during approximately six weeks in both the kindergarten and first grade. These lessons were first field tested at one volunteer school during Spring 1991. At the end of the spring semester, all 64 elementary schools in AISD were invited to apply for the pilot program in Design Technology. From the resulting 22 applicants, 15 schools were selected to use the preliminary DTEACH lessons and to receive materials kits, based on levels of interest and participation in other science programs (e.g., science clubs). The 120 volunteer teachers using the lessons during the 1991-92 school year have varied their scheduling and structuring of the lessons, but generally have taught the pilot DTEACH curriculum during the science/social studies time block every day for six to ten weeks. The following sections describe the basic components of the pilot curriculum, including instructional concepts and teacher training.

1) Concepts, Processes and Products in the Pilot Curriculum: In this section, examples of the concepts, processes, and products are listed for the kindergarten, first grade, and second grade pilot curriculum. Figure 1 schematically illustrates the applied science and engineering domains that are addressed by the DTEACH curriculum. To date, the curriculum includes lessons on materials, structures, mechanisms, and fluid power (the top three domains in Figure 1). Figure 2 provides a further breakdown of the kindergarten, first grade, and second grade lessons according to the categories of materials, structures, mechanisms, and energy.

In the pilot curriculum, kindergarten students learn concepts related to: combining and changing materials, and using connectors; recognizing and classifying materials made of plastic, wood, cloth, paper and metal; investigating properties of flexibility (elasticity) and strength; identifying and making wheels and axles (fixed and free-rotating); analyzing structures (especially empty cereal boxes) as to the number of surfaces and shapes of surfaces; and making predictions of flattened box configurations. Using these concepts, kindergarten children work on the following engineering design process skills: learning to work in teams of two; analyzing their teamwork and

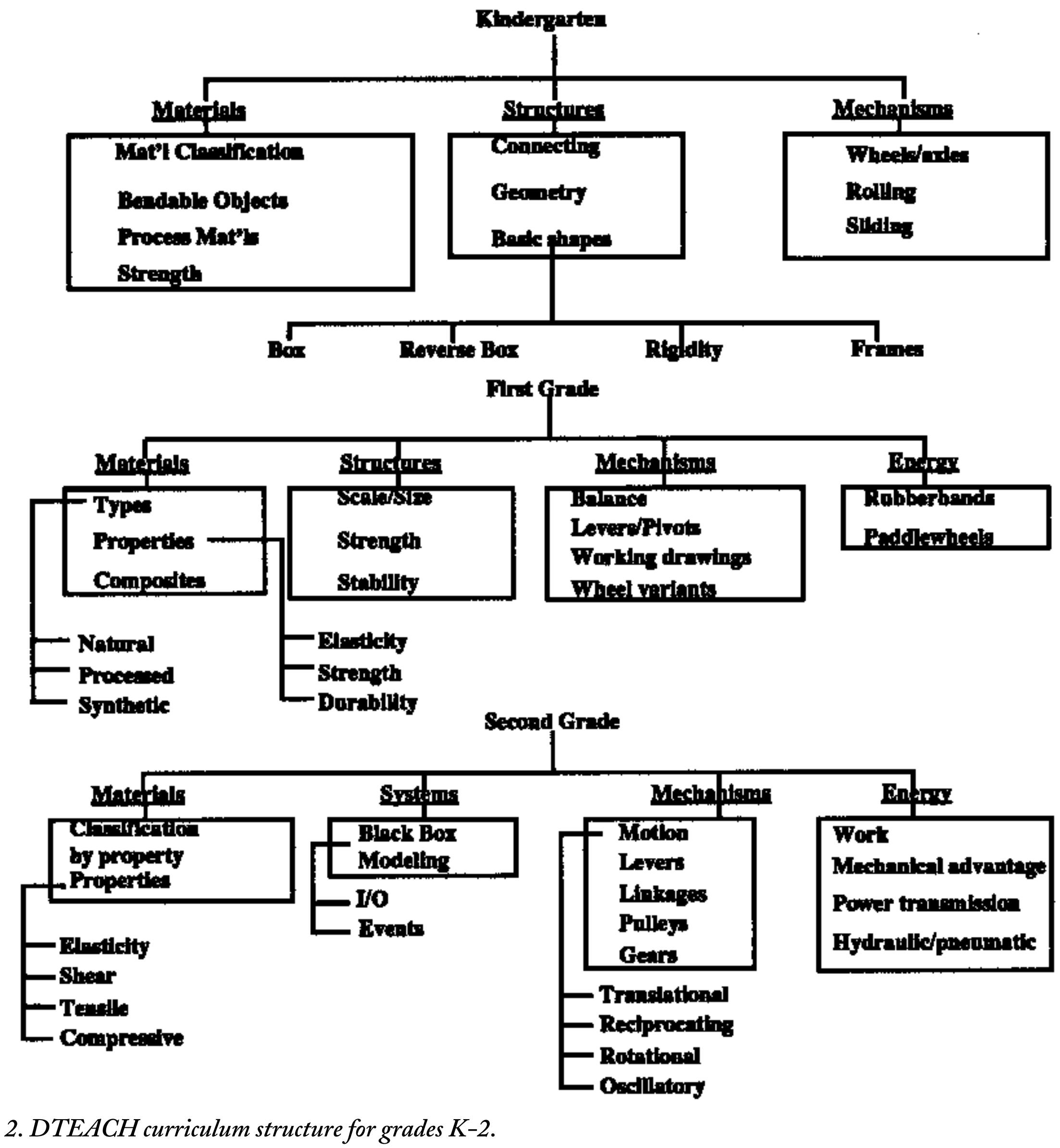

Figure 2. DTEACH curriculum structure for grades K-2.

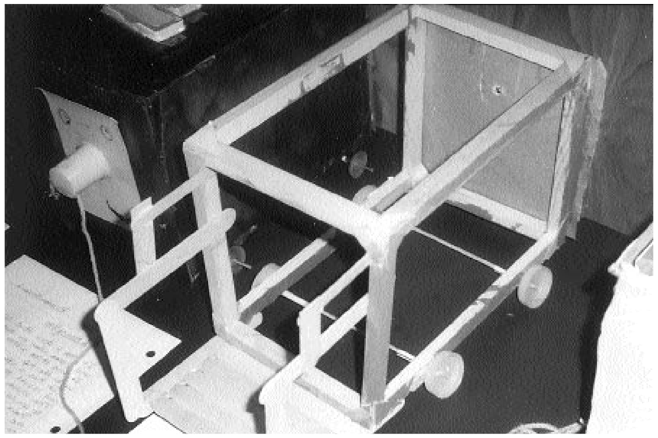

Figure 3. Products resulting from kindergarten design brief.

Figure 4. Products resulting from first grade design brief.

sharing interesting jobs; dictating descriptions of their products and the process; making and using simple blueprints; and evaluating as a group the team products and compliance with design specifications. Kindergarten lessons result in the following designed products: a toy that can bend and is made of at least three different materials; a wooden box frame; an inside-out cereal box; and a structure that can roll.

The photograph in Figure 3 illustrates one product designed and fabricated by a kindergarten team in response to the following design brief: "Make a frame that has an axle and wheels so that the frame will roll." This design brief appears in the latter part of the lessons and builds on prior lessons on materials, structures, and wheels. The product in the figure shows the incorporation of practical engineering concepts learned by the team, including the use of soda straws as axle carriers and the use of triangular gussets at the corners to strengthen the frame. In general, the teams demonstrate much creativity in individual choice of materials, decorations, configuration of the components, etc.

First grade DTEACH concepts include: recognizing and classifying materials that are natural versus synthetic and recyclable versus non-recyclable, including plastics that are accepted locally for recycling; identifying hybrid-heterogeneous materials (e.g., sandpaper) and structures; investigating balance, stability and durability; and identifying, designing, and constructing devices that move through the actions of levers and cams. First graders develop the following process skills: continuing the development and analysis of teamwork skills; writing descriptions of products and teamwork; understanding the use of small models to represent large objects; making and using simple sketches (blueprints) for planning; and evaluating the teamwork, products, and compliance with design specifications. First grade designed products include: making a "small model of a big thing" (a scale model), using both synthetic and natural materials; making a "mechanimal" (a mechanical animal) that illustrates literature or other studies, and has at least one part that moves using levers; creating a pop-up scene from the context of other lessons (e.g., a recent story read by the teacher) that uses at least one cam and one lever to make it move; and making a child's push toy that is safe, pleasing to look at, and has one or more moving parts.

The photograph in Figure 4 illustrates one team's response to the design brief: "Design and make a toy that is safe, pleasing to look at, and has one or more than one moving part." This design brief is the last lesson in the first grade curriculum and is the subject of the non-competitive technology fair (analogous to a science fair) that is the culmination of each of the units. The team's product, "Spot the Duck", is a powered floating toy that builds on prior lessons on rubber band power. The theme chosen for the design and its decorations again illustrate the creativity that elementary students utilize to solve open-ended problems. The description the students wrote to explain their design illustrates their grasp of the science concepts underlying the design: "The feet spin. You twist the rubber band to make energy. When the feet move they should make the duck swim.".

In addition to the piloted kindergarten and first grade lessons, preliminary second grade lessons have been written and piloted (Spring 1992) by four teachers at one volunteering school. This unit develops ideas of black-box modeling, power transmission through gears, pulleys, hydraulic and pneumatic power/energy, leading to team responses in solving a design problem, i.e., creating a mechanism to raise a sunken toy boat.

B. Structure of the DTEACH Lessons

The DTEACH lessons are structured into units, or "learning experiences", that allow the teacher to present engineering concepts incrementally to the students. Each learning experience consists of several lessons that emphasize different aspects of a particular concept. The lessons in one unit culminate in a design brief that allows the students to combine the engineering concepts with their own creativity to solve a design problem.

For example, the third learning experience in the first grade lessons focuses on levers and mechanisms. In the first lesson in this learning experience, the students explore the concepts of balance and mechanical advantage by experimenting with posterboard levers. The lessons include a discussion of common applications of levers. The second lesson in the unit is an exercise in black box modeling, in which the students deduce how a "movable greeting card" works. The card has one part, such as a bell, that can be moved with a lever. The mechanism is hidden by the card, and the students work in teams to determine how the card operates. The teams then work together to construct their own cards. The third lesson in the unit is a design brief in which the students design and build a "mechanimal" that has at least one part that moves using levers.

1) Integrating Mathematics Concepts: The DTEACH lessons provide a natural forum for illustrating practical applications of mathematics concepts studied by the students. For example, constructing their solutions to design briefs requires the students to measure materials carefully, providing practical experience in units of measurement. The teacher can emphasize the equivalence of English and SI units by requiring the students to use both in their design plans. Another example is the first grade lesson on levers, described above, which provides the opportunity for students to explore proportionality and the meaning of equations (balancing two expressions). A second grade lesson on designing experiments for measuring material properties provides a vehicle for studying experimental error with statistics (computing averages and variances) and for using graphical techniques to understand physical relationships by plotting the results of experiments.

The DTEACH curriculum also forms a synergistic program with other curricula taught in elementary and middle school. For example, elementary students are currently learning "hands-on algebra" in some school programs. The open-ended design problems of DTEACH complement such programs by reinforcing the hands-on approach to learning mathematics skills, as well as by demonstrating the link between mathematics and other subject areas. Figure 5 illustrates an example of intuitive mathematical and science concepts afforded by DTEACH in grade 2. Notice in the figure that basic engineering and technology concepts taught in the lessons are used by the students to develop design alternatives (the crane mechanism with a correct gear ratio—Figure 5).

C. Expansion of the DTEACH Educational Program

Based upon the successes of the grades K-2 DTEACH lessons, it is clear that the DTEACH Program must expand in at least two directions: more schools need to adopt the program, and the lessons must be expanded to include the upper elementary grades. The teacher enhancement program, described in section E below, provides a natural vehicle for expanding the curriculum to more schools. As part of this component of the program, participants have been solicited throughout the central Texas area, drawing teachers from within and outside the Austin area. In the first year of the teacher enhancement program, about half of the participants were teachers who had not previously taught the DTEACH lessons. Most of these participants expressed their enthusiasm about incorporating DTEACH into their curricula. Additionally, the authors have adopted a strategy of targeting specific schools to enroll multiple participants for the teacher enhancement program. This strategy is based on the observation that a new program has a better chance of success when more than one teacher is willing to introduce the program at a given school.

For expansion of the curriculum itself, conceptual subject areas in engineering have been laid out for the remaining elementary grades, third through sixth. A discussion of these subject areas is presented below, emphasizing the respective engineering concepts and process skills.

1) Curriculum Development, Grades 3-6: The DTEACH curriculum for grades 3-6 will review and expand upon kindergarten, first grade, and second grade concepts and skills, and will also introduce several new subject areas and skills. Third graders will continue the concentration on mechanical engi-

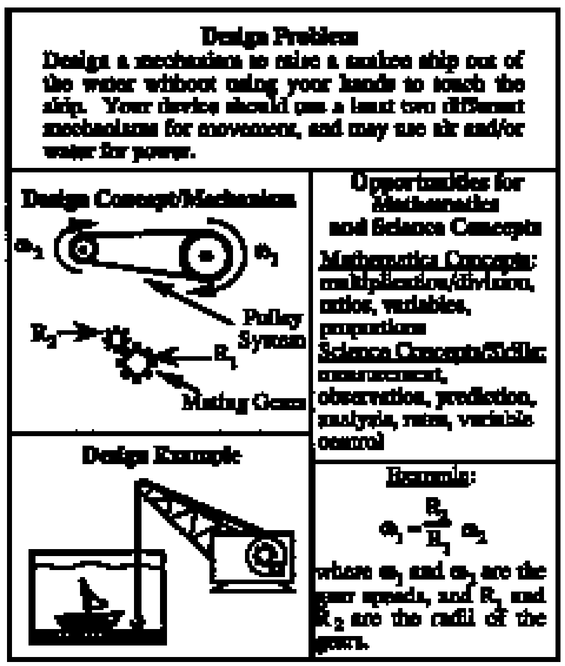

Figure 5. Example of integrating of mathematics/science in DTEACH.

neering concepts. In this unit, advanced mechanisms are presented, thermal properties of materials are exploited in the design of thermal systems, and the concept of sensing physical phenomena, particularly heat, is introduced. The uses of chemical energy processes will also be presented. Related mathematical and science concepts in this grade level include: multiplication and fractions (introduced with the idea of scale drawings) and heat flow (introduced with the observation of vaporization and condensation of fluids). Primary engineering concepts include: materials—alloys, thermal properties; energy—kinetic, thermal, chemical; structures and systems—power transmission, sensors; economics—cost/benefit trade-offs; and mechanisms—valves, pistons, clutches, air conditioners, etc. Primary process skills include: black box modeling, 3-D sketches, scale drawings, invention and innovation, and prototyping.

The fourth grade lessons will begin the transition from largely mechanical systems to electrical and electromechanical systems. The use of stylized notations for communicating technical concepts, such as circuit diagrams, will be introduced. Basic controls will be discussed and applied by the students. Mathematical and science concepts that will be illustrated include the balancing of values to determine the voltage in a circuit, and electron flow, through the operation of a direct current circuit. Primary engineering concepts include: materials—conductors, resistors, etc.; energy—electrical, transformation of energy; structures and systems—circuits, switches, resonance, electromechanical systems, sensors and actuators; mechanisms—transmissions, etc.; ergonomics—safety, human-machine interface; information processing—control. Primary process skills include: black box modeling and functional decomposition, diagramming electrical and mechanical systems, and troubleshooting.

The fifth grade lessons will continue the focus on electrical systems by presenting an introduction to electronics, with an emphasis on design with integrated circuits and the distinction between analog and digital. The issues of product life cycles, including materials recycling, product retirement, etc. will be discussed. Students will also be introduced to concepts of time management for team design projects. Example mathematical and science concepts that will be reinforced include binary numbers, through truth tables and the use of circuits, and environmental impact analysis of materials cycling through the ecosystem. Primary engineering concepts include: materials—semiconductors, material structures, crystals, integrated circuits; energy—amplification, photovoltaic energy; structures and systems—electronic components and circuits, gates, transistors; economics—life cycle issues; information processing—electronic control, analog/digital systems. Primary process skills include: logic diagramming and time management.

The sixth grade lessons will concentrate on the use of computer technology in engineering design. Students will develop software schemes that will produce a desired outcome, such as the specified motion of a linkage or crane system. Important concepts that will be developed in this grade include modeling of physical systems using the basic engineering concepts from grades K-5. For example, a physical model of a crane in terms of its mass, degrees of freedom, and so on must be understood before a specified motion can be achieved. Example mathematical and science principles include iteration from computer software, and science/society implications of information technology. Primary engineering concepts include: materials—computer languages; energy—compilation; structures and systems—computer systems; information processing—geometric modeling, simulation. Primary process skills include: programming, black box modeling for computer programming, computer-aided design, and use of the computer as a planning tool.

D. The Issue of Grade Level Appropriateness

A major concern of any educational program is the academic level of material covered by the lessons. Does the material target only certain segments of the student population such as gifted students, females versus males, etc.? Are the lessons too complex or complicated? Are the pragmatic steps of a hands-on curriculum so difficult or cumbersome that they obscure the mathematics, science, or other themes of the lessons? A close scrutiny of the DTEACH subjects, introduced above, indicates that the subjects are very similar, at least in name, to the subjects taught at an undergraduate engineering level. If the intent is to cover the material at the same level as an undergraduate program, then, of course, the material level is inappropriate for elementary students. However, this is not the intent of DTEACH. The DTEACH materials introduce very basic technology that the students encounter in their everyday experience. Teachers are encouraged to use the DTEACH technologies as a forum for teaching the basic science concepts of the given grade level. They provide hands-on materials that are prepared to the level of students being taught. This applies equally to the more advanced scientific concepts, such as electricity and electronics, that are currently taught in the higher elementary grades. For such science principles that are not as readily apparent as mechanics or material properties, the need for concrete examples is more critical in order to effectively convey the concepts. Using hands-on design experiences appropriate for the grade level places males and females on a level "playing field", allows *all* students to create useful designs, and provides gifted students with an open-ended forum for applying their creativity.

Overall, the lesson plans, outlined above, focus on an integrated development of basic engineering design skills, combined with hands-on mathematics and science. An important issue of this integration activity is provision for different levels of student proficiency. This issue will be addressed by organizing and presenting the material uniformly to all students, but providing for different levels of performance in open-ended problem-solving activities.

E. Teacher Education Component

An important component of any curriculum is the facility for teacher training and preparation. As part of the DTEACH curriculum, a teacher training component has been initiated through support of the Eisenhower Foundation (October 1992). The teacher training prepares teachers of grades K-6 in general problem-solving and design methodologies, selected subjects in engineering, and real-world applications of current technology. The purpose of the training is to provide participants with sufficient content in engineering fundamentals to allow them to understand the principles upon which the DTEACH lessons are based; the training component is not a workshop on how the lessons should be taught. The DTEACH lessons are used to provide focus for the training, but the training sessions explore the engineering subjects in more depth than do the lessons. Teachers in all grades obtain virtually identical training, both in engineering fundamentals and design methodology. This assures that teachers in the sixth grade, for example, are taught the material covered earlier in the design technology curriculum, and vice versa.

1) The Academic-Year Session: The intent of this course is to present the basic concepts of problem-solving, design methodology, and creativity, along with an introduction to engineering fundamentals. The course consists of lectures devoted to these concepts, with supplementary materials including laboratory group exercises in design problems and pertinent videos from national professional societies. The session consists of nine five-hour days of instruction over nine months, resulting in 45 contact hours (equivalent to a three semester-hour course).

Engineering design can be loosely defined as a problem-solving process that utilizes basic principles from science and mathematics. This course demonstrates how general process skills can be focused to a methodology for engineering design. Definitions and orientation of general engineering, followed by particular engineering disciplines, begin this stage. Creativity as an integral facet of design is addressed following these introductory definitions. Techniques such as brainstorming are taught and practiced by the teachers. Following the general topic of creativity, a particular design methodology is introduced. This methodology, developed by Pahl and Beitz[13], is founded on the concept that design is a process of developing functional descriptions of design solutions, transforming these functional descriptions to form (or physical) descriptions, and finally choosing the most feasible design for further development and construction. This methodology is generally characterized as a decomposition strategy—the design problem is decomposed into subproblems. Five general process steps comprise Pahl and Beitz's design methodology: (1) problem definition and clarification (including the generation of design specifications); (2) process description and functional description, generation of solution variants to the design subfunctions, and combination of solution variants into overall configurations; (3) developing preliminary layouts, selecting the most feasible configuration, and embodying this configuration; (4) optimizing the selected configuration; (5) and detailing the solution for production or fabrication. Case studies, example problems, and group laboratory exercises will be used as vehicles for learning this methodology.

For the remainder of the academic year session, the participants concentrate on specific engineering principles. The purpose is to provide the necessary background for understanding the technical issues upon which the DTEACH lessons are based. In this session, a range of engineering fundamentals are taught, including: mathematics (algebra, geometry, vectors, introductory trigonometry, etc.); materials science (types of materials, properties of materials, material selection, etc.); statics (free-body diagrams, forces and moments, equilibrium, etc.); solid mechanics (elasticity, tension, compression, etc.); and mechanisms and machine components (linkages, cams, gears, etc.). Teachers are given design exercises for each of the topic areas and hands-on experiences are provided using design kits and other supplementary materials. It should be noted that the intention of this session is not to cover the topic areas in complete detail. Instead, the fundamentals are presented as they relate directly with the DTEACH curriculum.

2) The Summer Institute: In a three week summer institute, participants concentrate on specific topics in engineering. The session consists of nine five-hour days focusing on: work and energy (elastic potential energy, gravitational potential energy, kinetic energy, friction, etc.); fluid mechanics (properties of fluids, hydrostatics, buoyancy, pumps and valves, Bernoulli's equation, etc.); and electricity (resistive circuits, Ohm's law, Kirchoff's laws, switches and relays, etc.). Each week of the session focuses on one of these topic areas. Each day consists of a number of activities including formal lectures, manipulation and discussion of materials related to the topic area, and group laboratory exercises. For homework, participants are ask to bring examples of devices from home that illustrate the engineering principles taught. Each day of the session begins with a roundtable discussion of these devices, including which engineering principles are utilized in the design and operation of the devices.

3) Teaching Model: The teaching model for teacher enhancement courses is designed to complement the model that provides the structure for the DTEACH lessons. The model emphasizes hands-on and exploratory learning as opposed to isolated lectures, thus stressing the role of the teacher as one of a guide and consultant. For each primary topic to be taught, the steps in the model are:

- Introduce goals, terminology, mathematics fundamentals and science fundamentals for a primary topic.
- Show background overheads of example technologies based on the topic.
- Manipulate hands-on and real world materials for primary topic.
- Divide material for a primary topic area into subtopics.
- Teach (interactive lecture) material for each subtopic (one subtopic per day).
- Perform open-ended laboratories on each subtopic.
- Debrief, collect materials produced from labs, and distribute to class participants.
- Perform open-ended design laboratory using all subtopics.

4) Observations of DTEACH Teacher Education: The teacher education program is designed not only to introduce teachers to the design lessons and basic engineering technologies, but to extend the teachers' knowledge beyond the lessons. This idea is philosophically valid in that the teachers will have advanced skills compared with their students. Such a skill level will equip the teachers with the ability to answer difficult questions and prepare new materials beyond the subjects covered by DTEACH. While the philosophy is valid, the reality of teaching elementary teachers raises some interesting issues. First, teaching the fundamentals of engineering requires a certain level of science and mathematics skills, usually at high-school or pre-college level (algebra, trigonometry, vectors, coordinate systems, Newton's Laws, etc.). Elementary-school teachers have limited background in these subjects, and usually have not applied these subjects during their careers. Second, while the intent is not to stereotype, it has been observed the elementary teachers tend to be very pragmatic. They want to see directly how the teacher education will benefit them in the classroom. If this link to their teaching methods is not clearly defined, teachers may become very frustrated and uninterested in the teacher enhancement education. Third, teachers need to be introduced to hands-on design problems (much like the lessons) so that they can plan the hands-on experiences for their students. Laboratory exercises for teachers will provide experiences with basic construction tools, and introduce the teachers to the difficulties of producing the form of a design concept. Such exercises also allow teachers to think about the related mathematics and science principles. If the teachers do not clearly understand and plan the instruction of these principles, DTEACH may become more of an entertainment forum for the elementary students, not a forum for learning applied science and mathematics concepts.

These issues make it paramount that a teacher education program be flexible and open to the elementary teacher needs. For instance, the first academic year session we taught for teachers covered a review of high-school mathematics over a five hour period. Although the mathematics was motivated by real engineering problems, a percentage of the teachers found it difficult to understand how these mathematics would be used in the elementary classroom. Likewise, since the teachers had not seen the material for many years (in some cases), the basic concepts were very difficult to cover in any depth and were frustrating to the teachers. To address this issue, subsequent lectures and laboratory exercises in the academic year session integrated the mathematics and science concepts directly with the DTEACH materials. Subjects such as structures for kindergarten, first grade, and second grade were introduced through a general lecture, and covered in depth with hands-on exercises and homework.

Overall, we cannot forego the idea of teaching elementary teachers beyond the level of the DTEACH materials; however, we must be sensitive to teacher needs and characteristics. The teacher education program should be based on a similar hands-on methodology that the teachers will use to teach their students. For example, through the design laboratories, many of the teachers developed a new-found belief in their own abilities. They realized they are capable of much more than the traditional stereotype of elementary school teachers. The stereotype that anyone who is not "technologically" gifted cannot construct something as "complicated" as an electric circuit, or design and create a working mechanism, is shown to be resoundingly false.

IV. Summary: Impact of DTEACH

The DTEACH curriculum promises to fill existing gaps in elementary science and mathematics education in many ways. At the very least, students are provided with hands-on experience in engineering, mathematics, science, and technology that is sorely lacking in the current "book-learning" or narrative approaches. Such hands-on experience has been proven to work in similar, smaller-scale curricula. For example, there is the case of a teacher who was recently recognized for her teaching method[14]: "Terry Kirchler, a teacher at the Drake Middle School, Auburn, Alabama, has been selected for an *IEEE Spectrum Precollege Innovative Math/Science Education Award* for instilling 'a lasting interest for science in her students.' In Kirchler's view,. . .book learning is not the answer [to children's fading interest in science]. Students simply grow bored with rote memorization and tend to drop their science courses at the first opportunity." To counter this, "she presents a new hands-on challenge to the students in her science units and requires them to resolve it."

If this case is any indication, a more ambitious program that begins hands-on design at the earliest stage of elementary education and systematically develops the curriculum through middle school has the potential for an even greater and more profound impact on our educational system. Students will understand math and sciences through the challenge of doing and applying, not by passively observing and listening from a seat in a classroom.

Beyond hands-on experience for mathematics and science instruction, the DTEACH program provides an avenue for elementary-level teachers to improve their expertise. Many of the teachers do not have extensive backgrounds in mathematics and science. Even if they have taken college-level courses in mathematics and science, teachers have difficulty in relating basic principles to the technology that they and their students encounter in everyday life. This simply means that the book knowledge of math/science is readily apparent, but not the intuition and understanding of underlying concepts and applications. The DTEACH program trains and encourages teachers to relate, substantively, classroom exercises to current events and to devices that students understand, such as developmental toys. The program also fosters curiosity and interest in technology that many teachers will pass on to their students. The observed result, in many cases, is a dramatic increase in spatial skills and the confidence to investigate the engineering and technology that saturates our existence.

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VI. References

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