Current Editor:
Richard A. Walter raw18@psu.edu

Spring 2002 **Volume 39, Number 3**

Children Designing & Engineering: Contextual Learning Units in Primary Design and Technology

Patricia Hutchinson
The College of New Jersey

The Children Designing & Engineering (CD&E) Project at the College of New Jersey is a collaborative effort of the College's Center for Design and Technology and the New Jersey Chamber of Commerce. The Project, funded by the National Science Foundation (NSF), has been charged to develop instructional materials for grades K-5. The twelve thematic units under development integrate science, mathematics, technology and other content through design-and-make activities. Activities are coordinated with both state and national standards and are situated within contexts inspired by seven New Jersey businesses. Project staff members are also attempting to explore how design-based activities can provide an early orientation to skills and attitudes sought by employers.

The CD&E project began in 1998 as a three-year effort to help elementary teachers incorporate design and technology into their teaching. Project collaborators from the College of New Jersey and the New Jersey Chamber of Commerce joined forces to design real-world, developmentally appropriate instructional units that would communicate the unique nature of technological pursuits and harness the inherent appeal of design activity as a vehicle for learning. The approach taken to the CD&E units draws on research from a wide range of current educational orientations, with the most notable among these found in the literature on contextual learning and problem-based learning. Underlying the materials is a general constructivist perspective, and units feature elements of authentic assessment and cooperative learning. Theories about workplace contexts, learning styles, and multiple intelligences have also informed our design decisions. In this paper, I will describe how the CD&E project applies theories of contextual learning, problem-based learning, and Design and Technology (D&T) education to create an amalgam of the three which we call Design & Technology-Based Contextual Learning.

Unique Nature of Contextual Units in D&T

Contextual learning units, viewed from a D&T perspective, are somewhat different from typical thematic units in that technological design is employed as both content and pedagogy. Themes are often thought of as a way to bring the "real world" into the classroom, although fantasy or speculative worlds can also be engaging to students, especially in early elementary school. Non-technological thematic units for elementary schools take a subject, perhaps "The Rainforest" (a topic within the science curriculum) or *Paddles to the Sea* (a book scheduled for study), and expand that topic into a theme for coordinating lessons in several subject arenas. Within the rainforest theme, teachers can coordinate subjects like science, art, reading, and geography. Teachers create thematic units by bringing together and adapting activities within their own repertoire, or purchase commercially developed units that provide coordinated activities and resources in one curriculum package.

A theme becomes a context when it is sufficiently pervasive and engaging that the classroom is transformed into a different kind of setting, one that transports students to a new environment for learning. This may be accomplished partly by changing the look of the physical space to continually reinforce the "feeling" of the context, but the real key is that subjects studied within the context are not just coordinated, but are *integrated*. To achieve integration, the context needs to have an embedded task, problem, or challenge for which students develop "ownership." Knowledge introduced within that context must be useful in completing the task, solving the problem, or meeting the challenge. The problem, task, or challenge can be of many different kinds-scientific, artistic, mathematical, technical, ethical-and so will engage students in different types of inquiry and processes, drawing pertinent information from a variety of fields in each case. The contextual learning units developed by the CD&E Project all feature technological challenges within real-world contexts that require students to apply targeted scientific, mathematical, and technical knowledge, as well as design, communication, and collaboration skills.

The following paragraphs provide a brief summary of three learning theories that inform the CD&E approach: contextual learning, problem-based learning, and D&T education.

Contextual Learning

From early in the 20th century, there has been talk about the de-contextualized nature of learning in schools. Whitehead (1929) used the term "inert learning" to describe a situation in which students memorize definitions of concepts without having the opportunity to apply those concepts in real-world settings. Educational psychologist E.L. Thorndike (1922), writing about mathematical thinking, blamed the disconnect between the classroom and the outside world on the content itself, citing some subjects long deemed to be good mental exercise as simply too removed from the skills and knowledge needed for everyday life. Dewey (1916) addressed both content and context by envisioning a type of schooling where real-world activities form the setting for meaningful learning. Many educators have tried to follow in Dewey's footsteps over the past century, although changes in our society have necessitated continuously redefining those necessary skills and knowledge.

Borko and Putnam (2000) have described contextual learning as situated, distributed, and authentic. All learning, they suggest, takes place (is *situated*) in specific physical and social contexts, and the knowledge acquired in those settings is intimately associated with those settings. For transfer of learning to occur, students must be given multiple similar experiences in which the similarities are made explicit and an abstract mental model is allowed to form (Greeno, 1997).

The setting in which learning takes place is comprised of many elements, all of which contribute to our understanding. Therefore, learning is *distributed* over all these elements (Borko & Putnam, 2000), including not only the understandings and attitudes we bring to a situation, but also the physical environment, other people, tools, and symbols.

The third component of contextual learning described by Borko and Putnam is the use of *authentic* activities-activities similar to those that take place in the real world outside of school. Newmann and Wehlage (1993) suggest that authentic activities have five dimensions:

1. They involve higher order thinking, in that students have to manipulate information and ideas.
2. They require a depth of knowledge, in order for students to apply what they know.
3. They are connected to the world in such a way that they take on personal meaning.
4. They require substantive communication among students.
5. They support achievement by all, in that they communicate high expectations of everyone, with each individual contributing to the success of the group.

Problem-solving, the everyday work of the real world, is an attribute of contextual leaning. To understand the relationship of problem-solving to learning, however, it is necessary to refer to another field of inquiry.

Problem-Based Learning

Problem-based learning (Barrows, 1985) is an instructional approach originally developed to help medical students learn to diagnose illnesses. Students are presented with a problem situation and asked to determine what is happening. Problem-solving, in this approach, involves a process of a) engagement; b) inquiry and investigation; c) performance; and d) debriefing, as described by Stepien (1995).

Both contextual learning and problem-based learning can be seen as continua, moving from a low to a high degree of application. Highly contextualized problem-based learning, the optimal meeting of the two perspectives, features:

- A focus on questions/problems relating to real-world issues.
- Self-directed and collaborative learning.
- Teachers and students as co-investigators/co-learners.
- Ongoing dialogue with practicing experts.
- Manipulation of real data.
- Exploration of a real workplace, or other real setting through actual or virtual visits, with opportunities to revisit.
- Ongoing formative assessment as well as performance before an outside (expert) audience.
- Comprehensive debriefing. (Pierce & Jones, 2000, p. 79)

Design and Technology-Based Learning

A third model, which represents aspects of the preceding two, has been developed over the past three decades in the United Kingdom. This approach, called Design and Technology (D&T), describes a special instance, or possibly a sub-set, of contextual problem-based learning, characterized by:

- The use of materials, tools and systems for making or modifying things.
- Products, systems, and environments as outputs of the learning process.
- Engagement with authentic problems or situations which seem genuine to students.
- Choice-making, and thereby the need to confront values issues.
- The flexible use of a range of procedural strategies (design process) to identify and solve problems.
- The interdependence of product and process in shaping learning. (Kelly, et al., 1987)

The Design Loop

D&T as a learning strategy employs a design process similar to the problem-solving process described in problem-based learning. D&T, however, emphasizes practical planning and physical making as necessary sub-activities of the process, as indicated by the model in Figure 1.

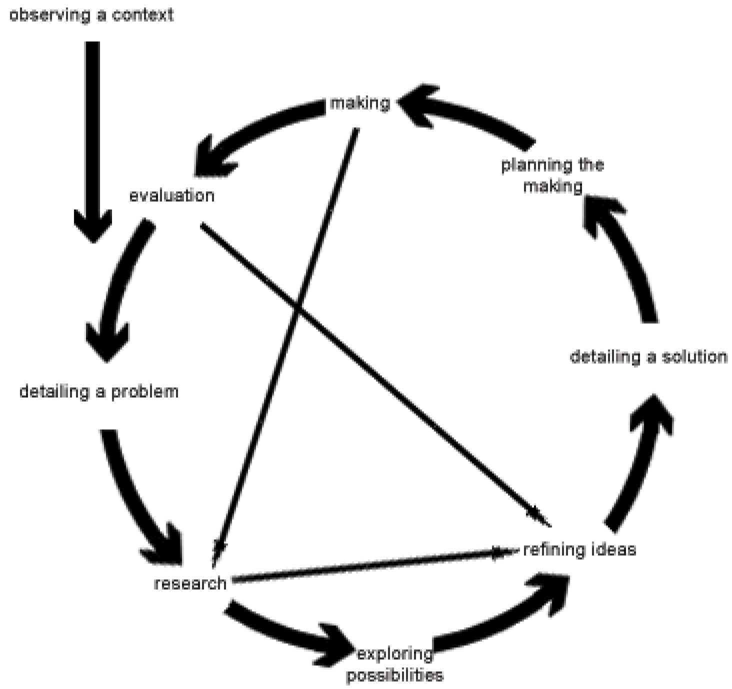

Figure 1. The Design Loop (Hutchinson & Karsnitz, 1994) Used with permission.

The design loop is a variation on the design line, a model often cited in art education, in which a bothersome-or promising-situation is detected (problem identification) and analyzed in order to clarify the real nature of the problem or opportunity within it. Once the problem can be clearly described in a "design brief," the designer can begin to articulate a plan. This design brief includes a charge to action ("Design and make a ___") and set of specifications (criteria for success along with constraints or limitations). Research, supplementing what is known about the problem, begins here and continues throughout the design process.

While the human mind tends to begin envisioning solutions almost as soon as a dissonant situation is detected, a clear picture of the problem allows the designer to apply idea-generating strategies (e.g., brainstorming) in productive ways. Experienced designers force themselves to consider multiple solutions to a given problem before evaluating and then choosing or adapting an approach. From this "ideation" phase, the designer begins to plan the execution of the idea, works out technical details, and marshals the resources needed to realize the envisioned solution. Sketches, diagrams, and lists are among the visible tools of this planning. Realization (the "making" stage) is carried out through early models (akin to early drafts in writing) which are tested, refined, and superceded by more finished versions until the solution is completed.

A solution is tested by applying it to the problem for which it was designed, and modifications are often required before a problem is considered solved. Publicly presenting the solution and subjecting it to open critique may expose problems missed by the designer. These steps are always included when design is employed as a learning strategy.

Because applying the solution may reveal other problems, and because the background situation of the problem may change, D&T theorists typically portray the design line as a design loop-or even a design spiral-to emphasize the iterative nature of design. That yesterday's solution can always be superceded and improved upon (taken "back to the drawing board") is consistent with our cultural conception of progress.

No designer would characterize the solution of a specific problem in the lock-step terms suggested by the design line, but most subscribe to the model as generally descriptive of the process. The arrows that cross the loop and allow two-way traffic between various steps illustrate the flexibility of the process. Technical planning may reveal the need for more research, and new insights into the very nature of the problem may emerge from the making process.

The Interaction of Hand and Mind

Technological design activity always results in tangible outcomes (products, systems, or environments) with physical modeling and mental processes-reflecting, critiquing, envisioning-as interdependent elements of learning.

D&T-based learning refers to the human ability to transform ideas into physical realities. This process of purposeful change, described by Kelly, et. al. (1987) is "a conscious capacity that can be both cognitive (manipulating ideas in the mind) and concrete (manipulating materials to model ideas)" (p. 12). The progressive concretizing (modeling) of ideas is externalized through sketches, drawings, diagrams, and physical models, using tools and materials. These authors contend that "this crucial relationship between the activities inside and outside our minds is interactive rather than sequential, and the total activity is cumulative, experiential and reflective as ideas are tried out and then accepted, modified, or rejected" (p. 12).

A model of this interaction offered by Kelly, et al. (Figure 2) suggests the growth of understanding that takes place through the designing and making process. The zigzag path charts the progress of an idea from a nascent glimmer in the mind's eye, shallowly conceived and lacking detail, through progressively refined articulations and increasingly concrete models.

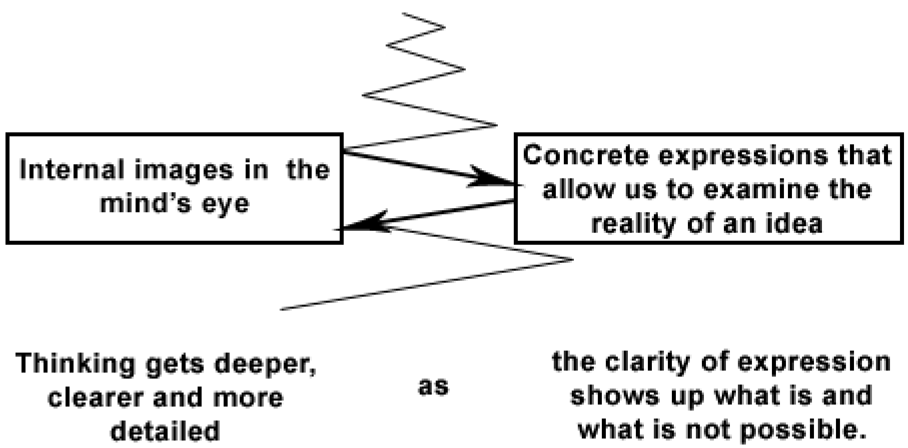

Figure 2. Relationship of reflection and action in design activity (Kelly, et al., 1987). Used with permission.

Although the progressive nature of creative development portrayed by this model would resonate with designers of non-physical products-a poem, a dance, an advertising slogan or, for that matter, a learning theory-it is the unique interdependence of hand and mind which distinguishes technological activity from other kinds of design activities. This aspect of D&T education is important for several reasons. First, it expands upon the means of expression available to students, a real advantage from the point of view of theories of multiple intelligences and differing learning styles. Second, interaction with the material world, especially in young students, is instinctively appealing and rewarding. It provides expanded sensory stimulation which, when applied in the context of intellectually stimulating problems, enriches the learning experience. Finally, from the point of view of evaluating student learning, D&T activity supplements spoken language and the written word with images and physical models as documentation of the learning process. This residue allows for a much more authentic assessment of the journey a student has taken through the process of recognizing or accepting a challenge and progressively coming to grips with meeting that challenge.

Combining contextual, problem-based learning with the features of D&T education allows us to implement a hybrid approach: Design and Technology-Based Contextual Learning.

Overview of the CD&E Units

The recognition of the central role of design in technological activity is relatively new in this country. The *Standards for Technological Literacy*, released by the International Technology Education Association (2000), have articulated that role and the importance of design activity as a teaching and learning strategy. Against that backdrop, the College of New Jersey (TCNJ) and the New Jersey Chamber of Commerce (NJCC) were funded in 1998 to create instructional materials for elementary schools featuring integrated learning situated in business-inspired contexts.

The units are intended to engage children in practical design and problem-solving requiring understandings from math, science, and other subjects, while also providing an early introduction to careers and to qualities valued in the workplace.

In choosing industry partners, the CD&E Project strove to include companies that would enable units to represent a range of sciences-life sciences, earth science, physics, and chemistry-since a major concern of our funding agent, the NSF, was the ability of these units to enhance students' understanding of science. The career awareness goals of the project dictated that the units would also represent major employment sectors in the state, leading us to approach and secure the partner companies listed below:

- Six Flags Wild Safari (entertainment)
- Lucent Technologies (communications/R&D)
- Marcal Paper (manufacturing)
- Johnson & Johnson (pharmaceuticals)
- Ocean Spray Cranberry Products (food production)
- Public Service Electric and Gas Company (power utility)
- Elizabethtown Water Company (water utility)

Table 1 provides a brief summary of the twelve CD&E units that have been developed.

Table 1. *Overview of CD&E Units*

Unit title	Unit description
Opening Day at the Safari Park Six Flags Unit, grades K-2	After a video safari park tour, pupils design and make a classroom safari park. They learn about African animals, natural and built environments, structures, and systems for communication and transportation; transform their room; then plan an opening day celebration and sell tickets to cover the costs of food and souvenirs.
Camp Koala Six Flags Unit, grades 3-5	Students design and make a visitors' center for Camp Koala, a new home for an endangered species that is being planned for a local safari park. Topics include endangerment of animals and impacts of technology as well as technical methods for creating moving displays. They stage a "Koala Gala" to publicize and raise funds for wildlife preservation.
Bright Ideas Playhouse Lucent Unit, K-2	Students explore properties of light, then apply what they've learned to design and make shadow puppet plays based on familiar nursery rhymes, to which they invite guests and charge admission.
Say It with Light, Inc. Lucent Unit, grades 3-5	As employees of a communication company, students learn about the roles of scientists, designers, engineers and marketing professionals in developing products. They investigate light and communication, then work as interdisciplinary teams to propose new products that use light for communication and present their ideas to the company's directors.
Earth-Friendly Greetings Marcal Unit, grades K-2	Students study the waste stream and recycle paper products into new paper, from which they design and make original greeting cards to sell at a class holiday boutique.
Paper Products: You Be the Judge	After investigating the claims made by companies about their paper products, students design and carry

Marcal Unit, grades 3-5	out scientific tests, then present their findings in a classroom version of *Consumer Reports*.
Waterworks for Watertown Elizabethtown Water Unit, grades K-2	Students study science (water cycle, gravity, flow) and technology (reservoirs, pumps, pipes, valves) in order to understand the needs of citizens of "Watertown" and design a system to deliver water to selected locations.
Solar-Powered Energy Savers Public Service Electric & Gas Unit, grades 3-5	The local power company has commissioned the class to design solar-powered "give-aways" to publicize and promote energy conservation for a community event. Students explore solar heat and electricity generation, then model and present their ideas.
Cranberry Harvest Festival Ocean Spray Unit, grades K-2	A video visit to a berry farm sets the stage for hands-on exploration of the special qualities of cranberries. Students propose devices and methods to harvest, sort and grade berries, then plan and stage a cranberry festival.
Juice Caboose Ocean Spray Unit, grades 3-5	Students learn how companies gauge consumer preferences and explore the physiology of taste in order to propose a new combination juice drink, then mass-produce, package, promote, and launch the product.
Germbusters & Co. Johnson & Johnson, grades K-2	Young students learn how germs travel and how various products and practices help control their spread. Then, enlisted by fictional heroine Gina the Germbuster, they make soap, test toothpaste, tissues and bandages, and design Germbuster Kits for themselves and other children their age.
Suds Shop Johnson & Johnson, grades 3-5	Students delve more deeply into germs and hygiene, then focus their attention on soaps and detergents. They learn about the chemistry of mixtures, suspensions and emulsions; investigate consumer product preferences, packaging, promotion, pricing and profit; then design and make soaps for the "Suds Shop."

Design of the Units

The CD&E Project was carried out in three phases: design, development, and evaluation. Upon receipt of the award, a project "home team" consisting of TCNJ project staff, an NJCC representative, and several advisory teachers was established and began meetings to discuss the scope, content, and approach of the planned units.

Design Phase

NJCC representative Dana Egreczky cultivated business partners while TCNJ staff pulled together industry-specific unit teams (e.g., Six Flags team, Lucent team, etc.). Each team (comprised of elementary teachers, curriculum writers, math, science and technology subject specialists, industry and Chamber representatives, and a videographer) was charged with the design of a K-2 and a 3-5 unit. In preparation for business site visits, packages of readings were assembled and distributed, including guidelines for looking at companies through the lenses of "technology," "science," and "business." This required studying and then distilling curriculum standards and other sources into concise conceptual frameworks for each of these perspectives. The team also developed policies on scope, content, and format of the envisioned units, initially deciding on six- and eight-week units, with a week envisioned as five 45-minute sessions.

The goal of designing to address standards offered special challenges. At the beginning of the project, no national standards for technology had been released. National standards in science and mathematics were written for three-year grade ranges. To interpret these standards with greater grade-level focus, team members reviewed three of the major science and math textbooks for each grade and developed interpretive matrices that were added to the package of readings and design tools given to unit design teams. Background readings on contextual learning, design-based learning, multiple intelligences, and constructivism were also included in the packages.

To explore the work of the partner companies, six unit teams carried out visits to seven companies between September, 1998 and November, 2000. At these site visits, industry hosts explained the activities of the company and discussed issues related to operations, economics, personnel, work environment, and other factors. Each fact-finding outing ended with a brainstorming session in which team members discussed what they had seen, offered tentative ideas for instructional units or activities, and identified questions for further research. Team members divided into two grade-level groups. Each team member was assigned the task of envisioning three possible units and naming each in terms of a tangible outcome-a product or system (e.g., a device to communicate with light), an event (e.g., opening day at the safari park), or an environment (Camp Koala). For each title, a list of weekly foci were requested, along with the beginning of an outline for the unit. Team members also cited standards to be addressed and began listing possible activities to be included in the units. These products were submitted to the CD&E team, reviewed and critiqued, and then incorporated in (or rejected from) development plans prepared for summer writing workshops, and selected unit team members were invited to move into the development phase.

Development Phase

Curriculum writing workshops were carried out during the summers of 1999, 2000, and 2001, with project staff developing and refining the materials during the intervening months. Context-setting videos were envisioned as the units developed, some taking the shape of "virtual field trips," while the need for other kinds of scene setting devices became clear as the models for units proliferated.

Three major milestones, each a solution to a problem, marked the development phase of the project. Early versions of units were too ambitious in scale, and by summer of 2000, the project was in danger of sinking under the sheer weight of ideas that could be included in a given unit. It was at this point, two years into the project, that consultants Malcolm Welch (Canada) and David Barlex (UK) were brought in to critique the drafts. The two had collaborated on similar projects in both the UK and Canada, and advised us to apply a rule of thumb to our decision-making. They suggested we clearly articulate a single "big challenge" for each unit and then include only content that would directly help students meet the challenge. Their work with similar units for process-based science and technology featured big questions and big challenges, respectively. This advice proved to be extremely helpful in focusing our work and bringing the units down to a workable scale, as did the suggestion to limit the units to four to six weeks.

A second problem was the scarcity of math experts who could appreciate the application of their subject to practical problem-solving and could recognize and translate engineering mathematics for such young children. Dr. Cathy Liebars, a mathematics professor who had been serving as a consultant to the project, reviewed the units to help optimize math application and suggested the formation of a team of her curriculum students. In Spring of 2000, Cathy marshaled the forces of four senior mathematics students and supervised them in writing supplemental math activities that could articulate and reinforce mathematics concepts applied in the units. These supplemental math lessons were added to the CD&E units with the suggestion that they be used, as needed, in math periods during a unit to reinforce math concepts.

The burden of writing and editing large numbers of lesson plans was made easier and more manageable in late 2000 by the addition to the team of graphic design and production specialist Lori Lozinski. Working with team curriculum specialist Ellen Farr, the lesson elements were streamlined and all developing units were brought into a single format.

By late 2000, several units were ready for pilot testing. Bright Ideas Playhouse, Earth-Friendly Greeting Cards, Opening Day at the Safari Park, Camp Koala and Say It with Light, Inc., were given trial runs in several New Jersey schools. An ad in *TIES Magazine* soliciting interest in remote piloting resulted in responses from forty states, far more than the project could accommodate. Questionnaires returned by pilot teachers were very helpful in refining the units.

Instructional Design Considerations

It was originally imagined that units developing out of workplace contexts could be similarly structured, based on a single instructional model. In that model, students would experience a virtual visit to the company, then proceed to create a classroom version of the business, with the "big challenge" to produce a K-2 or 3-5 version of the company's product or service. In such a model, learning is situated in the authentic technological problems addressed by the company.

Interaction with Six Flags Wild Safari, the first company to join the CD&E partnership, reinforced this model, although it was clear that few other companies would have the natural appeal for young children presented by the safari park. The park could easily be interpreted in terms of technological problems: housing, feeding, protecting, and transporting animals and people. Each example provided opportunities for learning about and applying ideas from life sciences, physics, and mathematics. In the Six Flags model, weekly activities for both the K-2 and 3-5 units were designed around technology content: structures, mechanisms, transportation and communication systems, environmental and event design. Weekly projects provided components of the envisioned environment, which was then showcased in a culminating event. This event included authentic commercial aspects, with tickets for admission, a gift shop and refreshments and an external audience of other students, parents, and local business people, who were asked to evaluate the event through a customer survey.

From the earliest piloting efforts, the Six Flags units proved to be popular with both students and teachers. Interaction with subsequent businesses, however, revealed the difficulty in applying a standard model to all units. Although all businesses provide some type of product or service, few of these can be easily and engagingly adapted to the elementary classroom, and it became clear that each business needed to be examined for its unique learning opportunities and interpreted in terms that would capture the imagination of young students. Design team members from the various companies, many of whom were also parents, contributed significantly to identifying a range of perspectives on their businesses and eventually six types of units evolved (Table 2).

Table 2. Major Business-Inspired Foci of Units

Business Activities	Units
R&D	Germbusters & Co. Say it With Light Solar Energy Savers Let's Produce Juice
Production	Earth-Friendly Greeting Cards Suds Shop
Event Design	Bright Ideas Playhouse Cranberry Harvest Festival
Environmental Engineering	Safari Park Camp Koala
System Simulation	Waterworks for Watertown
Product Testing	Paper Towels: Kidsumer Report

Many of these activities overlap in the various units. For example, a largely R&D unit will have some production and product testing aspects. All units have a culminating event, although planning of the events becomes a design focus in Bright Ideas Playhouse and the Cranberry Harvest Festival. Although it would certainly have been easier to construct units using a single blueprint, we feel that the range of approaches we've developed provides a much richer vision of the many activities of industry, and allows us to identify aspects of each company that appeal more directly to children.

Despite the differing emphases of the units, basic tenets of the CD&E vision have remained consistent. Each unit begins with a context setting device in the form of a video, a book, a game or an interactive story on CD-ROM. Initial engagement is followed by presentation of the big challenge, which the teacher helps the students "unpack"- analyze and begin to build ownership of. A KWFL chart, included in most units, prompts students to list what they Know about the subject, what they Want to know to begin to solve the problem, and where they might Find this information. The "L" column, what they have Learned, is revisited as they work their way through useful learning activities. In this problem-analysis activity, the teacher essentially leads the class through a preview of the topics that will be covered in the unit.

Diverse knowledge needed to meet the challenge is acquired in a variety of ways, including research and experimentation, demonstration and practice, following directions to learn a technique, and constrained problem-solving. Smaller component problems are solved to build toward a cumulative outcome, or a range of learning experiences are brought together in the solution of one major problem. In each unit a culminating business-oriented event, to which an outside audience is invited, is staged.

Also common to all units is the opportunity for students to work both individually and in teams. Each unit includes suggested components for a classroom resource center, and as the unit progresses the environment of the classroom becomes increasingly rich and theme-focused. All students are introduced to a simplified design model and practice using the process as they solve increasingly demanding problems. Teachers are urged to assume a collaborative role and to use questioning techniques to help students make decisions. Opportunities are provided for the class to stop at natural intervals in their projects, to step back and reflect, to share what they are making and what they have learned, and to critique their own and their classmates work.

The K-2 units that have emerged in CD&E take a broad approach to subject matter; grade 3-5 units focus on a more discrete aspect of the topic, allowing greater depth of exploration. For example, in the five-week Safari Park unit for grades K-2, weekly topics include:

Week 1 -	Introduction to the challenge with a video visit to the Safari Park
Week 2 -	Investigating, designing, and making structures for animals
Week 3 -	Investigating, designing, and making things for workers and visitors (e.g., clothing, tools, rules)
Week 4 -	Investigating, designing, and making safari park vehicles
Week 5 -	Planning and carrying out an opening day celebration

In the Safari Park, learning content and meeting the big design challenge are interwoven activities. The challenge is met cumulatively as the classroom environment grows over the entire five weeks. More advanced units at grades 3-5, such as Camp Koala, tend to require considerable information-gathering before design work begins. In this unit, students encounter the idea of endangered species and must envision how their safari park would accommodate a community of koalas. They then design a welcome center for Camp Koala with an interactive display to inform visitors about issues affecting the survival of koalas. To do this, they must learn about structures, mechanisms, and controlling movement, as well as exploring effective means of communication.

Each CD&E unit contains a teacher's guide, a guided student portfolio, and a kit of resources. A context-setting video is also provided for most units. The teacher's guide contains background on the project, a unit overview, weekly summaries, daily lesson plans, instruction sheets for various activities, transparency masters and templates, evaluation rubrics, and advice for adapting lessons for special needs. Guidance is also provided for customizing units in order to partner with local industries and to address state standards. Staff development, especially in technical and pedagogical areas not traditionally covered in elementary teacher training, will also be provided when the units reach the marketplace. Pilot testing has demonstrated the need for help with activities such as building with square section wood, making cardboard mechanisms, and wiring a circuit. Reviewers and pilot teachers have also requested examples of possible solutions to challenges, since many of them are unsure what results are realistic. These have been provided, where possible. Much attention has also been given to the graphic design of a user-friendly format for the units, and pilot testing suggests a level of success in meeting this goal.

Say It with Light, Inc.: A Case in Point

Say It with Light, Inc. is the name of a unit designed in collaboration with Lucent Technologies for the upper level of the 3-5 grade band. Lucent absorbed and superceded Bell Labs during the deregulation of the Bell Telephone network. Like Bell Labs, Lucent is a communications think tank whose product is ideas. The bulk of Lucent's creative energy goes into research in photonics. When asked what they would like upper elementary children to derive from a learning unit, Lucent representatives suggested the topic of communicating with light. Specifically, they wanted children to begin to understand the many dimensions of light that can be used to transmit information. Because both light and electricity are elements of national and state standards at fifth grade, the team targeted that grade level. Say It with Light, Inc. is the most challenging of the CD&E units. It is also the most time-consuming for classes that have had no prior experience with technology, since it requires technical drawing, modeling, and creating and controlling movement, each of which is taught within the unit.

To help teachers understand the structure of the unit, a simplified topic web is presented in the introductory material (Figure 3). The premise of the unit is that the students will become members of design teams for a company that makes communication products. The central box in the web contains the big challenge: to design and model a device that communicates with light, then present that idea to the company management for their approval as a new product. The smaller boxes highlight the content that must be understood and applied to meet that challenge. Teachers are urged to introduce the unit challenge and then use an analysis tool such as a KWFL chart to elicit from students what they feel they will need to know to solve the problem. In this way, the students see the connection to the content that they will explore in the coming weeks.

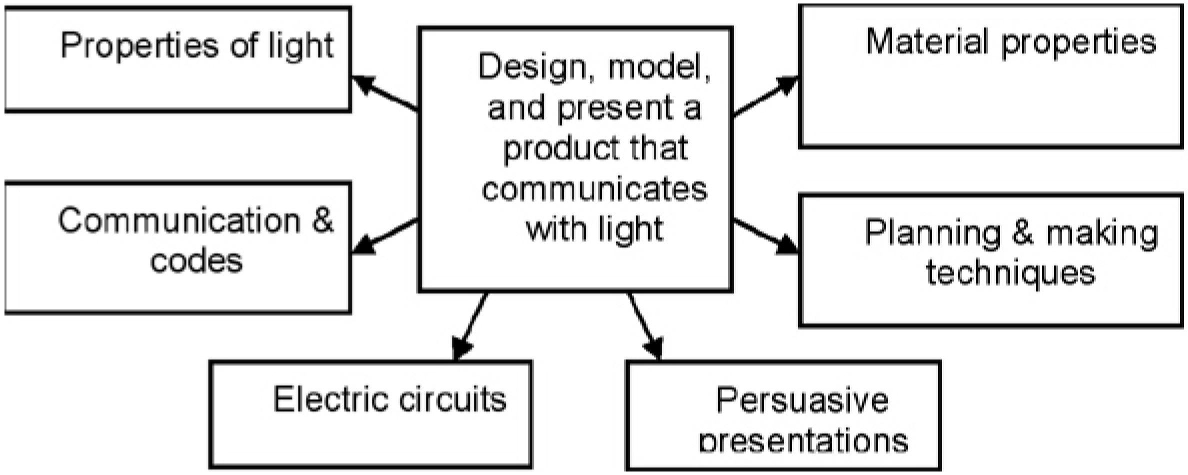

Figure 3. Say It With Light, Inc. Topic Web

Attempts were made in each unit to create fairly self-contained weekly topics that would have a degree of closure. The weekly topics for Say It With Light, Inc. are:

1. Communicating with Light: Lighthouses
2. Electricity and Light
3. Light, Materials, and Color
4. Designing a Communication Product
5. Making the Product
6. Presenting the Product

Week 1. Communicating with Light: Lighthouses

The unit is introduced with an exploration of the idea of communicating with light through a short design and make activity. In teams of four, the students are presented with the scenario that they have been shipwrecked on a deserted island and must build a tall tower to hold up a signal light. Each team is given newspapers and tape and in twenty minutes builds a tower that must hold a one-pound sandbag (lantern). The towers resulting from this energetic activity are evaluated using a simple rubric, and afterward the students are asked to discuss why a higher tower is better for sending a light signal than a lower one. Their discussion leads to a review of basic science principles: light travels in straight lines from a source; the curve of the earth will block a light signal at some distance; a source of light can be natural or artificial. The question of the relationship of height of the lighthouse to distance at sea from which the signal can be seen provides the opportunity to explore functions, with dependent and independent variables that can be plotted. A supplemental math lesson is provided to allow the teacher to explore this mathematical idea if she chooses. Functions are revisited at several other points in the unit, with supplemental lessons to reinforce this concept.

After this focusing activity, students work toward the week's goal of creating a display of New Jersey lighthouses.

They carry out historical research and prepare posters to present what they've learned. They perform experiments with lenses and reflectors to see how improvements in lighthouse technology over the centuries enhanced communication. They learn about eclipsers, the masks rotated around light sources that enable light patterns-codes-to be transmitted. The week's culminating event is the assembly of light house models with right angle gears to turn an eclipser around a self contained light unit. Class teams customize their models to represent the New Jersey lighthouses they've researched. Around the display, the students discuss what is meant by communication and are shown the unit's video, "Communicating with Light," a collage with music of real-world examples of light communication. In their portfolios they summarize what they have learned in science, technology, history, and math.

The week's activities are intended to take about five hours. During field testing, teachers reported that it took them considerably longer, but they felt that the experience was very rich and envisioned that it would be shorter the next time around. Technology concepts discussed include the ideas that technology solves practical problems and that newer technologies supercede and improve upon older ones. Students encounter a conceptual model including elements that apply to all communication technologies. They also investigate a mechanical system (gear train) to transmit energy and change the direction of motion, and they follow directions to assemble a device. Although they practice a design/make/evaluate process, the experience is not fully debriefed but is used to establish a pattern for upcoming design activities.

Week 2. Electricity and Light

Week two is the second of three weeks devoted largely to providing science content and other knowledge which can then be called upon to meet the big challenge. Week one reviewed basic properties of light, while week two focuses on light and electricity. The first session begins with the assembly by each student of a "credit card flashlight" from instructions. After building and testing, the students reverse engineer the product. They create a three-view drawing with dimensions and hidden lines. Because three-view drawing is an example of spatial manipulation (a mathematics content standard), a supplemental math lesson is also provided for teachers who want to reinforce this idea in their math session.

The three-view drawing allows students to isolate and investigate the LED-battery-switch assembly in the flashlight, which provides a lead-in to assembly of a circuit on a demonstration board. Students build and diagram a light circuit using 3-volt batteries, wires and alligator clips, and a bulb. They make a paper-clip switch and compare these components to those in their flashlight, noting what is essential in a circuit. They try several other components in their circuit to brighten and dim the light, and learn that this circuit can be discussed in terms of a system, an important idea in technology. The systems model to which they are introduced is identical to the model of a function machine used in mathematics, and a supplemental lesson for enlarging upon this idea in math class is provided.

The flashlight the children build allows them to further explore math and science principles. They revisit dependent and independent variables by moving their flashlight away from a wall incrementally and comparing the size and brightness of the area of illumination with the distance from the wall. They practice sending flashlight messages with Morse code, then consider ways to transmit light around corners using mirrors. To understand angles of incidence and reflection, they perform experiments and use a protractor to measure angles. Fiber optic cable is provided and students speculate on how it transmits light, then meet a challenge to send a message around the corner and into the next room using Morse code. The week ends in a discussion of new dimensions of light that might be used for communication.

Week 3. Light, Materials and Color

Students begin their third week exploring light by designing "lens-holder glasses" into which can be fit a variety of colored and special-effects filters, including star filters, refraction grating, and polarizing film. Portfolio pages guide them to note the visual effects these filters produce. This activity leads them into a discussion of the need for light to see and the physiology of the eye that allows people to see light, dark, and colors. They also earn that all colors are derived from white light and that the colors we assign to objects are the colors those objects reflect. Experiments are carried out looking at objects through filters, then with light projected through filters. Additive color theory is illustrated, and students use paints to experiment with subtractive color theory.

In the final two days of the third week, student teams apply what they have learned about color and filters to design and make a "hidden clues" board game, within a variety of constraints. One constraint is the need for a spinner or dice, and the idea of chance and probability in games is discussed; this provides an opportunity for a supplemental math lesson on probability. Once the games are completed, they are traded, played, and evaluated. The students know that they will soon begin designing their communication devices, and the week culminates with a discussion of ideas that are taking shape.

Week 4: Designing the Communication Product

Having acquired significant information about and techniques for using light, the students are now presented with a conceptual design model and are guided through the process of envisioning solutions to their communication problem. Three categories of communication devices are provided to help focus their efforts, two fairly directive and one more open. These include:

1. Design a device that uses light signals and code to help a parent tell a deaf child three different messages.
2. Design and model a holiday lantern that communicates a holiday message.
3. Design and model a new product of your choice that communicates a message with light.

Because this unit has been designed to provide insight into the workings of an R&D company, the students are introduced to the idea of design teams comprised of scientists, engineers, designers and marketing specialists. They carry out an activity to differentiate the contributions that each of these members might make to the design process, and decide which of these roles each wants to assume for their design team. By the end of the fourth week they have brainstormed ideas for their project, selected and developed one of these ideas, and found the resources they will need.

Week 5: Making the Product

During week five, the students practice several drawing techniques that will help them refine their ideas. Some may also build quick, preliminary models. Tool demonstrations are carried out. The students are checked out on the equipment they need and review the safety rules.

Standards of quality construction are also discussed, and students critically reflect on what constituted good workmanship on earlier projects such as the lighthouse, the flashlight, the glasses, and the game (all of these products are displayed around the classroom). The teams spend the remainder of the week building, testing, and improving their models. The week culminates with demonstrations and critiques of the models, which can still be improved before the final presentation.

Week 6: Presenting the Product

In the final week, students learn about making persuasive presentations, using charts and graphs, creating effective graphics, and using projectors and visual aids. They review rules for public speaking. Many presentation techniques are familiar from language arts, since oral presentation is a widely practiced component of both state and national standards. Evaluation forms for the audience are provided with the unit. The students make their presentations on the next to the last day of the unit, and during the final class session they review their evaluations, discuss what they have learned and how they might have improved upon their solutions, and celebrate their hard work with a light snack.

Evaluation of the CD&E Project

Four CD&E units were evaluated in the Washington Township School District in southern New Jersey. This district was selected for several reasons. The administration has worked with earlier projects of our design team, and some of their teachers served on CD&E unit design teams. The district supported the teachers in arranging their schedules to accommodate the rather demanding field test. The evaluation plan called for field testing each unit with a pair of partner teachers, one who had received training in D&T methods and one who had not. All teachers received instructional materials, videos, tools, and consumable resources and were provided one day's training before beginning work with their unit. All were compensated for their time above and beyond their typical work day.

Bright Ideas Playhouse was field tested in two first grade classrooms in Hurffville School; Opening Day at the Safari Park in two second grades at Whitman School; Camp Koala at one third grade, and Say It with Light, Inc. at two fifth grades at Birches School. One third grade teacher had to drop out of the field test because of illness.

Field tests took place between February and June, 2002. CD&E project evaluator Dr. Kenneth Welty of the University of Wisconsin, Stout, developed instruments for evaluation of science, math, and technology content targeted in unit objectives. These instruments are extremely user-friendly for young children and have been designed to test both factual knowledge and application of principles. Because of the reading ability of the youngest children, and the inclusion in all classes of special needs students, Dr. Welty "performed" the evaluations for some of the classes, using devices like shadow puppets, actual objects, and pictures on overheads to demonstrate his questions. Evaluation data collected during the five months of field testing is not tabulated as of this writing, but debriefings with the students after the testing suggests a high rate of understanding, particularly of the science concepts tested. Further comment can be made from interviews with teachers, observation of classes, discussion with students, and review of work in progress and final products generated by the classes.

Teachers were generally enthusiastic about their units and about the reactions of their students. Some noted that, while this type of unit takes more time than some teaching approaches, it is authentic and likely to provide more lasting learning. Most teachers felt that the units had addressed their science curriculum well. Fewer felt that the units taught math, although in all cases they felt that math processes and principles were applied. Those teachers with D&T training recognized the technology content beyond the building and making techniques, but most of the teachers who had not received D&T training were unclear about what constituted technology content.

Many students commented on what they had learned and, weeks after the end of the units, could talk at length about science concepts and about how much they liked designing and making things. Several students commented that this kind of schoolwork made them feel like grown-ups. When asked where they had learned a number of different science and technology concepts, they cited their own designing and making as the source of the understanding.

Conclusion

While significant bodies of research exist on contextual and problem-based learning, study of D&T-based learning is just beginning. Early observations are providing interesting results: schools in Philadelphia, Virginia, and Maryland, where teachers have been prepared through Project UPDATE (a previous NSF-funded project based at TCNJ) to use this method are showing overall gains on standardized tests (Todd & Hutchinson, 2000). Many of the effects reported anecdotally are also consistent with research findings summarized by Pierce and Jones on problem-based learning in science and mathematics, and its positive effects in the areas of motivation, self-direction, retention, conceptual transfer, small group collaboration, and teachers' attitudes (Pierce & Jones, 2000, p. 83).

Our experiences with the CD&E Project suggest some directions for research in Design and Technology, a critical need if the potential of this instructional approach is to be realized.

References

Barrows, H.S. (1985). *How to design a problem-based curriculum for the preclinical years*. New York: Springer Publishing Company.

Borko, H., & Putnam, R. T. (2000). The role of context in teacher learning and teacher education. In *Contextual teaching and learning: Preparing teachers to enhance student success in the workplace and beyond*, (pp. 34-67). Columbus, OH: ERIC Clearinghouse on Adult, Career and Vocational Education.

Dewey, J. (1916). *Democracy and education*. New York: Macmillan

Greeno, J.G. (1997). On claims that answer the wrong questions. *Educational Researcher*, 26(1), 5-17.

Hutchinson, J., & Karsnitz, J. (1994) *Design and problem-solving in technology*. Albany: Delmar Publishers, Inc.

International Technology Education Association. (2000). *Standards for technological literacy: Content for the study of technology*. Reston, VA: International Technology Education Association.

Kelly, A.V., Kimbell, R. A., Patterson, V.J., Saxton J., & Stables, K. (1987). *Design and technological activity: A framework for assessment*. London:Assessment of Performance Unit of the Department of Education and Science.

Newmann, F. M., & Wehlage, G.G. (1993). Five standards of authentic instruction. *Educational Leadership*, 50 (7), 8-12.

Pierce, J. W., & Jones, B. F. (2000). Problem-based learning: Learning and teaching in the context of problems. In *Contextual teaching and learning: Preparing teachers to enhance student success in the workplace and beyond* (pp. 69-95). Columbus, OH: ERIC Clearinghouse on Adult, Career and Vocational Education.

Stepien, W.J. (1995). *A guide for designing problem-based instructional materials*. Aurora, IL: Illinois Mathematics and Science Academy.

Thorndike, E.L. (1922). *The psychology of arithmetic*. New York: MacMillan.

Todd, R., & Hutchinson, P. (2000). The transfer of design and technology to the United States. In R. Kimbell (Ed.), *Proceedings of the DATA Millennium Conference*, (pp. 215-222). London: Design and Technology Association.

Whitehead, A.N. (1929). *The aims of education*. New York: MacMillan.

Hutchinson (hutchinp@tcnj.edu) is Director of the Center for Design and Technology in the Department of Technological Studies at The College of New Jersey in Ewing, NJ.
