New Tools for Design

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> **True inventions require the determination to solve multiple problems in order to overcome contradictions and yield creative solutions.**

Introduction—Design as a Continuum

Design and the design process constitute nearly half of *Standards for Technological Literacy* (ITEA, 2000/2002), and technology educators are deeply committed to teaching the design process. This process can be thought of as spanning a continuum of difficulty, with routine problem solving at one end and inventive problem solving at the other (Committee for Study of Invention, 2004).

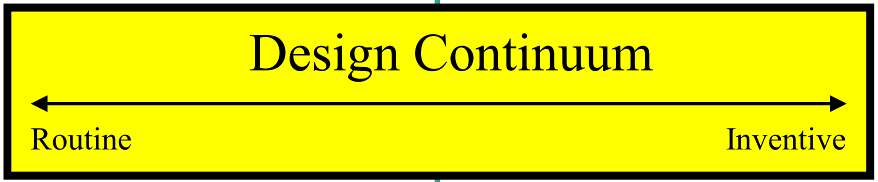


Figure 1. The Design Continuum

Routine problem solving often follows systematic procedures for diagnosing familiar problems and prescribing known solutions, with *systematic* being a key component. Solutions to routine problems usually come from the base of knowledge possessed by the individual, the company or, in the case of education, the classroom. In the technology education classroom, problems may take the form of design briefs; solutions may come from the knowledge received through instruction.

The routine end of the design continuum is characterized by:

- Brief searches for similar problems (problem definition)
- Brief searches for an "off the shelf" solution that might fit the problem, and
- A small number of trials.

Much of our curriculum is composed of the application of standard solutions to routine problems—but this does not mean that the process is simple, easy, or mundane. All phases of design and engineering require skill and creativity (Adams, 1991). Well-written design briefs present challenging and exciting problems that can be solved by students applying standard solutions in new and unusual ways.

A challenge to technology education curriculum developers and teachers is to decide what, if anything, to teach differently on the inventive end of design, which is characterized by:

- The unknown (in the problem situation)
- Lengthy searches for the problem (problem definition)
- Lengthy searches for known solutions, and
- Many trials

The inventive end of the design continuum has two additional characteristics. Inventions require knowledge that often resides outside the individual, company, classroom, or field of study. The knowledge necessary to solve what appears to be a mechanical problem may be found in chemistry, electricity, or some other domain. A second characteristic is the presence of conflicting or contradictory design requirements. An inventive problem arises, for example, if a product must be both strong and lightweight—characteristics that usually necessitate a trade-off. Or it may be encumbered by requirements that are in direct conflict with one another, such as rigidity and flexibility.

Standards for Technological Literacy asks technology educators to prepare students with knowledge of the inventive end of the design continuum. What must technology educators teach to meet the additional requirements demanded by invention? What knowledge, tools, methods, and procedures are available to offer our students? How does this differ from the tools we commonly use at the routine end of the continuum?

We need to find a method for invention that meets the following criteria, which are derived from the characteristics listed above and include:

- Knowledge of the unknown (in the problem situation).
- A rapid and systematic search for the problem (problem definition).
- A rapid and systematic search for solution ideas.
- Reduced number of trials (If using only trial-and error-methods, inventions require hundreds or thousands of trials—a requirement beyond the time available to the classroom teacher).

Routine problems are routine because they are encountered frequently. Standard solutions are standard because they can be used to reliably solve routine problems. That the two are combined over and over again is a testament to the efforts of many people over many years in bringing them together. Routine problems and standard solutions, which are applied in a systematic manner, reduce the difficulty of teaching and learning problem-solving methods. A systematic approach to invention will reduce the difficulty of teaching and learning how to invent.

An effective method for invention will also be repeatable and reliable. It must be able to solve inventive problems over the entire spectrum of knowledge, and to reliably produce solutions.

Finally, this method of invention must not be exclusive to exceptional individuals. Technology educators must be able to learn, apply, and teach the principles and concepts of the method to all of their students. Fortunately, such a method exists.

TRIZ* a New Set of Tools for Invention

TRIZ

Although it may appear to be the new kid on the block, TRIZ has a long and interesting history. Its foundations extend back to 1946, with Genrich Altshuller's quest to develop a method for invention. Skeptical of the then-popular psychological methods for improving creativity, and finding that no other methods existed, Altshuller looked to the accumulated results of invention as documented in patents. Over a period of 40 years, Altshuller and his colleagues analyzed more than two million patents, making several important discoveries along the way. They defined a truly inventive problem as having one or more internal contradictions. They discovered that, contrary to the common notion that an invention is something new and unusual, there were identifiable patterns (more than 100) in the solutions to inventive problems. They discovered that technological systems evolve over time according to identifiable patterns, giving those who knew these patterns predictive power. Most importantly, they developed several methods and tools for applying this knowledge, then tested the validity of each discovery through extensive practical work solving tough technological problems. Altshuller and his colleagues established training and certification programs and educated hundreds of students in the use of his methods (Altshuller, 1999). He and his colleagues engaged in the continuous development of a science of invention until his health declined and the development of TRIZ passed entirely to his students and colleagues. TRIZ has continued to develop, and the community of TRIZ enthusiasts has grown worldwide. TRIZ concepts are used by professional inventors and engineers and are taught in colleges and universities. Profound enough for the professional, TRIZ principles have also been successfully learned and applied by children in elementary and secondary schools.[***][†]

Some TRIZ Tools and Principles

> "A problem well defined is a problem half solved."
> –Charles F. Kettering

From many years of observing people struggle to solve difficult problems, Altshuller concluded that people too often accept the problem as it is first formulated, then immediately begin searching for a solution. This tendency, sometimes called solution mindedness (Perkins, 2001), gets in the way of finding and solving the real problem. One of Altshuller's tools for defining a problem is called the *systems approach*.

The systems approach to problem definition is guided by a nine-cell matrix that incorporates the concepts of time and system depth as shown in Figure 2.

A problem might, upon first appearance, correspond to any of the nine cells. Nonetheless, the systems approach asks the inventor to examine all the cells before seeking a solution to the problem. This systematic search of possibilities

	Sub-system	**System**	**Super System**
Past	Past Sub-system	Past System	Past Super System
Present	Present Sub-system	Present System	Present Super System
Future	Future Sub-system	Future System	Future Super System

Figure 2. The Systems Approach Matrix

at the start of the problem-solving process pays off later. Consider, for example, a farmer who began encountering severe problems with a hay baler—the drive belts virtually exploded. Having previously tested the belts under a variety of conditions, the manufacturer initially focused on the load placed on the belts by that particular crop of hay, and the conditions (heat, humidity, moisture content of the hay, etc.) present in the environment. After their balers failed with a variety of crops and conditions in a number of fields, the manufacturer traced the problem to the belt manufacturer. In order to cut cost, the belt manufacturer had changed glue suppliers: the new glue reduced the effectiveness of the belts. Had the baler manufacturer been more systematic in identifying the problem at the outset, he would likely have avoided multiple baler failures and the resulting bankruptcy of his company.

> "It's the things you know, that aren't so, that will hurt you."
> –Anon.

Problem definition (or problem "finding") is a key ingredient for all types of problem solving. Altshuller's systems approach can help find problems located anywhere along the design continuum.

Systems Approach Activity

Because problem definition is so critical to solving inventive problems, and because it applies to the entire design continuum, students should practice identifying the hierarchical levels of systems and examining the history of each level. Teachers can present students with a product, along with a simple handout describing the systems approach, then ask students to complete the nine-cell matrix for that item.

TRIZ Discoveries

Altshuller's early discoveries—the presence of one or more contradictions in an inventive problem, the similarities in solutions according to identifiable patterns, and the patterns that govern the evolution of technological systems—provided the foundation for further development of TRIZ over the last 60 years. These discoveries can be applied in the technology education classroom; we'll offer a brief description of each as well as suggestions for related classroom activities. In addition, we'll look at the different levels into which inventive problems fall.

Definition of an Inventive Problem

After analyzing more than 200,000 patents, Altshuller noticed that many represented simple, incremental improvements created with readily-available knowledge. His interest was in "inventive" problems—those that led to considerable change in a technological system or even replaced it. This narrowed the number of targeted patents and precipitated the discovery that an inventive problem is one in which there is at least one **contradiction** (Terninko, 1998).

Altshuller identified two types of contradictions. A ***technical contradiction*** (commonly called a "trade-off") is a situation where an attempt to improve one feature of a system detracts from another. Outside of TRIZ, technical contradictions are most often resolved by compromise. A ***physical contradiction*** is one in which a system characteristic must exist in opposite states: it must be both large and small, or present and absent, or flexible and rigid, and so forth (Kaplan, 1996). TRIZ seeks to overcome contradictions rather than submit to compromise or trade-off.

Finding Contradictions

Problem finding is one of the basic skills of the inventor (Perkins, 2001) and, according to TRIZ, inventive problems contain one or more contradictions (Kaplan, 1996). Because a contradiction is a necessary condition of the inventive end of the design continuum, the ability to spot a contradiction is an important part of problem finding. Identifying contradictions can be consciously practiced, and teachers can structure this practice for their students.

Good-Bad Game

Contradictions in products and systems can be found by playing the Good-Bad game. One variation of this game entails selecting a product and asking, "What is good about this product?" and listing all the beneficial features and functions. The next step is to ask, "What is bad about this product?" and listing those features and functions. By playing this game one can find many bad features and functions in even the best products.

A second variation of the Good-Bad game is to select a product and again ask, "What is good about this product?" After receiving one answer, ask "What is bad about [the first answer]?" followed by "What is good about [the answer to the last question]?" and so on. It is almost always possible to find something bad about a good feature and vice versa.

If continued too long, the Good-Bad game can yield responses that seem silly; this should not distract you from the task, however. Albert Einstein once said, "If at first the idea is not absurd, then there is no hope for it." Many useful products that surround us are based on notions that were once considered impossible or absurd. The purpose of this game is to find contradictions. Products with characteristics that are both good and bad are fertile grounds for invention.

Contradiction Activity

Teachers often have administrative duties to attend to at the beginning or end of a class period. This is a good time to have students practice the Good-Bad game. It can be presented as a daily activity for students to engage in when they enter the classroom and their teacher is busy with attendance and other administrative activities. A product (or picture of a product) can be placed in a dedicated location in the room. Students can be instructed to individually play the Good-Bad game with that product and take notes about their thoughts. These notes could be kept in a special notebook that the teacher reviews occasionally. Alternatively, when the teacher is ready to begin class, the students could be asked to briefly share their results.

"Yes, but…" Indicator

When you are discussing an idea for solving a problem and someone says, "That's a good idea, but …" you have found a contradiction that needs to be resolved. It also means that the proposed solution has produced a secondary problem. Inventive problems often have many secondary problems that only appear when a solution is presented. True inventions require the determination to solve multiple problems in order to overcome contradictions and yield creative solutions. Students should learn to listen for the "yes, but…" indicator and identify the related contradiction and secondary problem.

Levels of Invention

In his search of the patent literature, Altshuller recognized that solutions fall into five categories according to the difficulty with which they were derived:

Level One—Standard
- Solutions that are obtained by methods well known within a specialty in an industry—no invention required.

Level Two—Improvement
- Improvement of an existing system, usually with some complication.
- Solution methods are obtained from the same industry.

Level Three—Invention inside the paradigm
- Essential improvement to an existing system.
- Solution methods are obtained from other fields or industries

Level Four—Invention outside the paradigm
- Creating a new generation of a system.
- Solution methods are obtained from science, not technology.

Level Five—Discovery
- Pioneer invention of an essentially new system.
- Usually based on a major discovery or new science (Kaplan, 1996).

Altshuller discovered that most patents belonged to Level One. As these did not represent solutions to inventive problems, he focused his attention on the remaining categories. From an initial group of more than 200,000 patents he identified approximately 40,000 that he deemed inventive. From these he sought to create a method that would guide problem-solvers toward truly inventive solutions.

Levels of Invention Activity

Classification is one of the basic steps in the development of scientific inquiry and also benefits the study of technological systems. Using Altshuller's system for classifying inventions, students can obtain an appreciation for the time and effort necessary for creating them. They can also better understand the need to explore beyond the limits of their current knowledge to solve problems.

Objective: To observe and understand the level of difficulty of technological inventions.

Assignment: Given a set of inventions selected by the teacher, students will classify them according to their level of inventiveness.

Analysis: Identify how the systems have been improved. Determine whether the improvements came from well-known sources or from sources outside the related industry. Identify whether the system was simply modified or fundamentally changed. Position the inventions according to their level of inventiveness, and justify your choices.

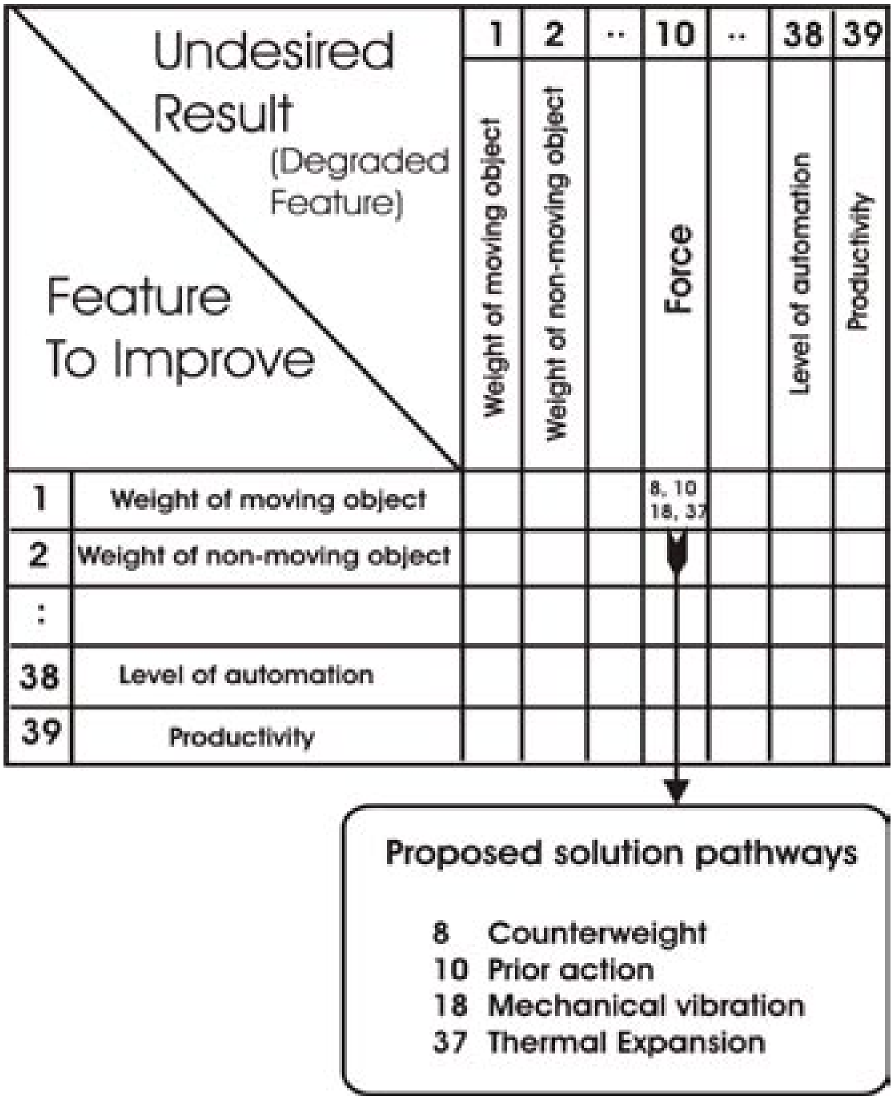
Present the conclusion and justification with a computer slide show and narration.

Examples could be posted on the bulletin board and/or presented to the class before beginning the assignment.

Evaluation could be based on a rubric designed by the teacher and the class.

Patterns of Invention

Altshuller discovered that true inventions overcame technical contradictions without compromise. He identified 39 engineering parameters such as strength, weight, area, volume, speed, force, etc. that often required trade-offs, and identified 40 inventive principles that had been used to overcome them. He then constructed the Contradiction Matrix—a tool for applying these



Undesired Result (Degraded Feature) / Feature To Improve		1 Weight of moving object	2 Weight of non-moving object	..	10 Force	..	38 Level of automation	39 Productivity
1	Weight of moving object				8, 10 18, 37			
2	Weight of non-moving object							
:								
38	Level of automation							
39	Productivity							

Proposed solution pathways

8	Counterweight
10	Prior action
18	Mechanical vibration
37	Thermal Expansion

Figure 3. A portion of the Contradiction Matrix (Kaplan, 1996)

principles to overcome technical contradictions.

The Contradiction Matrix lists the engineering parameters down 39 rows and across 39 columns. The cell at the intersection of two parameters represents a contradiction. Inside it are between one and four inventive principles ("pathways" for invention) commonly used to resolve that contradiction, listed in order of frequency of use. In Figure 3, the cell at the intersection of parameter 1 (weight of a moving object) and parameter 10 (force), contains inventive principles 8, 10, 18, and 37.

Forty Principles Student Activity

The contradiction matrix provides multiple opportunities for student activity and practice. Students can be presented with the principles and appropriate illustrations, then asked to provide their own illustrations from products addressed in the curriculum or found in everyday life. Students can present their illustrations to the class for discussion and evaluation. The complete Contradiction Matrix is beyond the scope of this paper; it can be found, along with an explanation of the 40 principles and numerous examples, in Kaplan (1996) and Altshuller (1997). An updated version of the matrix can be found in Mann (2003).

Separation Principles

In addition to discovering the 40 principles for resolving technical contradictions, Altshuller found that physical contradictions (two required characteristics in direct conflict with one another) could be overcome by applying what he called the *separation principles.* There are four separation principles:

- **Separation in time**—where a characteristic might be large at one time and small at another time; or present at one time and absent at another time. For example: *Pencils must make a mark when writing but not make a mark when being carried in a pocket, backpack, etc. The pencil lead, an element of the pencil, must have two conflicting characteristics—make a mark and not make a mark. The solution: a mechanical pencil resolves this contradiction using the separation in time principle by extending the lead from the body of the pencil for writing, and pulling the lead into the body of the pencil when not writing.*
- **Separation in space**—where a characteristic might be large in one place and small in another place; or present in one place and absent in another place. For example: *Small plastic bandages are required to stick to a wound*

but not stick to the scab. They are required to seal the wound and allow the skin to breathe. The solution: Different spaces on the bandage are assigned different characteristics. The ends of the plastic strip are sticky, and the pad of the bandage is covered with a nonstick surface. The sticky plastic adheres to the skin and contains a matrix of holes that allows the skin to breathe.

- **Separation on condition**—where a characteristic might behave one way under one condition and behave a different way under another condition. For example: *Eyeglass lenses must be clear to see well in normal light, but must be shaded to shield the eyes from excessive light. The solution: The chemistry of the lens darkens the lens under the condition of bright light.*
- **Separation between parts and the whole**—where a system might have a characteristic at the system level and an opposite characteristic at the part (or sub-system) level. For example: *A bicycle chain is required to be both flexible (so it can bend and move) and rigid (so it can transfer force). The solution: Each link in the chain is rigid, while the whole chain is flexible.*

Separation Principles Activity

Students can practice identifying the use of separation principles by studying products and tools from the curriculum or from everyday life. They can be asked to note how they see the principles applied and share their findings with the class.

Frequent practice identifying where the separation principles and the 40 principles have been used in products and systems helps students become more aware of their human-made environment and how it was created and improved.

Patterns of Technological Evolution

Altshuller discovered that technological systems change over time according to distinct patterns. For this reason, the eight patterns he identified have predictive power. An inventor who knows the developmental history of a product—and knows the patterns of evolution—can predict the future evolution of the product and use the patterns as guidelines for improving it. An overview of the patterns of evolution is beyond the scope of this article, however, even the use of simple timelines denoting changes in technical systems is of use in developing technological literacy.

Technological Evolution Activity

An effective learning activity can be designed around the patterns of evolution of technological systems. A timeline of a system's evolution can also be a useful tool in the technology classroom. By seeing how technology changes over time, students can learn to anticipate how things are likely to change in the future.

Objective: To observe and understand the evolution of technological systems, and to predict their future development.

Assignment: Complete a web quest and construct a timeline of the history of a selected technology.

Analysis: Identify and briefly describe major systems used in the technology. (Examples in sound recording are vinyl disks, magnetic tape, compact disks and memory chips.) Then identify the advances that were made within each system. (Examples with magnetic tape are reel-to-reel systems, eight-track cassettes, large cassettes, microcassettes and so forth.

Graph or chart the timelines to show dates and changes in the features of the systems. **Predict** the next development in the evolution of the technology, and justify your prediction.

Construct a mockup of the expected technology and explain its features and benefits.

Present your graph or chart, explanations, predictions and justifications with a computer slide show and narration. Examples are posted on the bulletin board.

Evaluation is based on a rubric designed by the teacher and/or the class.

Example: If the activity was designed around the recording and playing of sound or music, then the teacher can create a sample activity by doing a quick Web search and gathering several examples of sound recording and playing devices. These devices can be displayed and the teacher can point out how the changes followed the patterns of evolution. By understanding how technologies evolve, an inventor can predict the next likely evolutionary stage of a system or technology.

More information about the patterns of evolution can be found in Ideation International (1999), Zlotin (2001), and Halliburton (2004).

Ideality Pattern of Evolution

One of the several ways that technologies evolve is toward the "ideal." Altshuller called this pattern Ideality and defined it as the tendency of a system to provide more and more benefits (functions) along with fewer disadvantages—to the point where the system that provides the functions is no longer required. Ideality can therefore be described as a ratio, where the ideal is equal to all of the useful functions divided by all of the so-called harmful functions such as cost, energy consumption, undesired by-products, maintenance requirements, and so on.

$$\text{Ideality} = \frac{\text{All Useful Functions}}{\text{All Harmful Functions}}$$

(Kaplan, 1996)

Recognizing that technology evolves toward the ideal provides guidance in the search for improved or replacement technologies. There are two ways to move toward the ideal. One is by increasing the number and quality of the useful functions; the other is to eliminate or reduce the harmful functions. A superficial assessment of Ideality might suggest that it provides little guidance—adding useful functions or eliminating harmful functions seems obvious. But a more thorough understanding of Ideality reveals that simply adding useful effects or cutting cost will not necessarily increase the Ideality ratio. The addition of a useful effect often requires additional resources, which in turn increase cost and, potentially, increase harmful by-products or waste. Cost reduction often weakens the system and diminishes the useful effects. Indeed, Ideality is not so simple. Altshuller discovered that for a system to approach the ideal requires inventive solutions that make use of resources *already within the system*. Thus, one method for increasing ideality is a careful analysis of the system's resources to determine how they can be used more effectively, provide new functions, eliminate harmful effects, etc.

Ideality Illustration

To illustrate the principle of increasing ideality through the use of resources consider the simple system of a Styrofoam cup used to hold hot or cold drinks. The cups are easily manufactured in large quantity and at low cost but they are not free of harmful effects: The cups are unstable and can be easily tipped over and the contents spilled. A solution to this drawback is to use a thin plastic lid with a shape and flexibility that allow it to be fastened over the top of the cup. The lids are also easily manufactured in large quantity and at low cost. This

Type of Resource	Guiding Question
Function Resources	What functions of the cup might be used to make it more stable?
Field Resources	What field resources are present? Could a difference in temperature or gravity, for example, be used to help stabilize the cup?
Information Resources	What information does the system impart to us as it functions? Can we use this information to increase the cup's stability? Conversely, what information about the cup, were it available, could be used to make it more stable?
Idea Resources	What ideas have been used in other cup designs to make them more stable? Can we use these ideas—or variants of them—to increase the stability of our system?
Substance Resources	What substances exist in the system, and what properties do these substances have? Can any of this be used for stabilization?
Space and Shape Resources	What space or shape resources in and around the system might be used?
Time Resources	What happens to the cup over time? Does it stabilize or become less stable? Do any changes occur that might be used to increase stabilization?
Trend Resources	What trends might have an effect on the design of Styrofoam cups? What were these cups like in the past? What characteristics might they have in the future?

Table 1. A FIST of Resources

is an obvious solution, yet the cup remains unstable. So we must ask: What resources exist within the system—which consists of the foam cup and thin plastic lid—that can be used to remove this instability?

Our problem is to stabilize the cup. The instability seems to be a result of the ratio of the cup's height to its width at the base. Clearly, *shape* and *space* are resources of the cup—but how can they be changed to improve stability? One solution is to make the cup wider and shorter, yet hold the same volume. Another solution is to make the base of the cup much wider and the mouth smaller. How can we make the cup wider at the base? Since the cup is widest at the top, and the lid is wider than the top, perhaps we can use the lid to stabilize the cup. We could change the shape of the lid (again using the resource shape) to allow a press-fit to the bottom of the cup in the same way that the lid press-fits to the top of the cup. The lid may then be used as an attached saucer to stabilize the cup and/or collect a small spill.

System Resources

A system, like the cup and lid, can have many types of resources, and not all of them are readily apparent to the casual observer. The simple acronym FIST serves as a reminder that there are a "fistful" of resources that the inventor should look for. In Table 1 we examine these resources with respect to the cup-and-lid system.

Other resources may be included in the FIST table, and it is helpful for the inventor to remember that resources may be concentrated, combined, or used to derive additional resources.

Inventive Activity: Examine Current Products and Identify Resources

Identifying resources is a skill that can be taught, practiced, and assessed—starting from a very basic level and advancing to higher levels. It is essentially a search activity. We can think of a simple search activity as looking for information in a book. If the book's table of contents is sufficiently descriptive, a quick search can be easily accomplished. If the table of contents is inadequate, the searcher might resort to using the index. The FIST of Resources table is like a table of contents that guides the searcher to a number of resources within a product that might otherwise be overlooked.

Memory devices such as FIST can help students remember the various types of resources that exist, but they will still need to practice identifying resources. Activities can be built around simple everyday products to enable students to practice searching for resources. The FIST table provides a systematic way to search for resources and generate ideas for solving the problem. It also provides the technology teacher and student with specific content to teach and learn.

Inventive Activity: Reverse Engineer or Re-solve a Problem That has Been Solved

Present your students with a slotted flat head wood screw, a screwdriver, and an instruction sheet for using them. Typically this activity requires that three holes of different sizes and shapes be drilled in the board beforehand: one hole to accommodate the diameter of the shank of the screw (the shank hole), a second hole to accommodate the root diameter of the screw (the pilot hole), and a third hole to accommodate the flat head (the countersink). The primary purpose of the holes is to prevent the wood from splitting; they also prevent the screw from twisting in two as it is driven into the wood. Teachers can then present several problems to the students. Among them is to design a screw that:

- Does not split the wood.
- Leaves the head flush with the surface of the wood.
- Does not twist in two as it is driven.
- Prevents the driver from slipping off the head.

Multiple solutions to these problems can be purchased at hardware stores or lumber yards. The teacher might keep these in reserve as students search for resources within the screw that can be used or modified to solve the problems presented.

Alternative: Rather than asking your students to solve a problem that has already been solved, you might present several of the solutions you purchased at the hardware store, then ask them to identify how resources within the system (wood-screw) were used or modified to solve the problem.

Inventive Activity: Invent a Solution to a Current Problem

Inventing new products for the marketplace is an engaging experience for young students. Experience shows that even upper elementary students are capable of applying TRIZ principles and inventing new products that are marketable and even patentable.[***] Several state and national organizations have programs supporting inventive education, and sponsor state and national inventive competitions.

Few of these programs, however, teach the types of principles and skills found in TRIZ.

Assessing Learning

Because TRIZ has a broad knowledge base, a teacher can test to determine whether students know and are able to apply that knowledge in meaningful ways. Students can be asked to:

- Define an inventive problem.
- Define and identify a technical or physical contradiction.
- Identify resources in the FIST table.
- Define Ideality.
- Describe the harmful and useful functions of a product.
- Provide examples of the separation principles or the 40 principles at work in common products.

Students can be tasked to apply the inventive principles of TRIZ with inventive design briefs. They can then be asked: Have you accomplished the prescribed task? Have you applied the principles? Can you describe how the principles were applied? In this manner the technology teacher can assess a student's performance beyond the creation of a product.

Content for Teaching Invention

TRIZ provides the technology teacher and curriculum developer with content knowledge, principles, and skills for students to become inventive problem solvers. Students can learn:

- The definition of an inventive problem.
- How to identify different levels of invention.
- To identify contradictions.
- To distinguish between technical (trade-off) and physical (conflict) contradictions.
- The patterns of technological evolution.
- How a system might evolve in the future.
- How to identify unused resources in the system.

Students learning TRIZ will improve their skills and creativity when working with inventive problems and will improve their problem-solving skills at all positions of the design continuum. Students learning TRIZ will also begin to see that the principles can be applied to their everyday lives to solve problems outside the realm of technology.

Conclusion

TRIZ provides a powerful set of methods and tools for the inventive end of the design continuum. TRIZ meets the criteria for an inventive method—it can be directly taught and systematically applied by students. TRIZ provides knowledge of the unknown (in the problem situation) by helping the inventor identify characteristics of the system. It speeds the search for solutions by helping the inventor view the problem from all system levels. It provides a faster search for solution ideas by identifying available resources, and by providing methods for resolving contradictions. TRIZ reduces the number of trials the inventor would need to make by providing an index to methods that have worked in similar cases across many technological domains. TRIZ principles can be systematically applied to provide repeatable and reliable results for inventors themselves and for technology teachers who wish to make their students more inventive.

Sophisticated enough for the professional designer, engineer, and inventor, the TRIZ principles, methods, and tools can be used by elementary and secondary school students. With TRIZ, technology education teachers have knowledge content to help their students understand the inventive end of the design continuum at a deeper level than ever before.

This paper has provided a glimpse of the large knowledge base known as "classical" TRIZ. Many topics such as modeling, physical effects, fields, and psychological inertia have not been addressed. Modern TRIZ—or the Ideation/TRIZ methodology, which has been under development since 1986—expands the TRIZ principles to several hundred operators and lines of evolution, and is computer based for rapid access to a complete set of principles and tools.

Notes

* TRIZ, pronounced as "trees," is an acronym representing the Russian words *Teoriya Resheniya Izobretatelskikh Zadatch*, which translates to Theory of Inventive Problem Solving.

** The scenario is derived from conversations with a consulting agricultural engineer who worked with the manufacturer of the hay bailer.

*** The Entrepreneurs Grow on TRIZ program has demonstrated that, even with very brief instruction in the TRIZ principles, students in upper elementary, middle, and high school can apply the principles to invent marketable products.

† This assertion derives in part from conversations with Boris Zlotin, Alla Zusman and other TRIZ scientists at Ideation International about their experiences teaching TRIZ to youth.

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