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INTEGRATING TRIZ INTO THE CURRICULUM: AN EDUCATIONAL IMPERATIVE

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ABSTRACT

TRIZ, The Theory of Inventive Problem Solving, is a powerful methodology for producing systematic innovation and improving one's thinking processes. The application of TRIZ promises enormous benefits to society. Due to the history of its development, however, TRIZ is relatively unknown to educators in North American K-12 schools and institutions of higher education. This paper introduces TRIZ to educators by tracing the development of TRIZ from its origins to its present form. The paper also introduces the concept of ideality, one of the basic premises of TRIZ. Examples and case studies are provided to illustrate concepts and improve understanding about TRIZ. Issues related to curriculum development are discussed along with suggestions for systematic integration of TRIZ into K-12, college, and university curricula.

INTRODUCTION

Solving problems facing 21st century society demands creativity and innovation. Thus, community and government leaders are asking the question: "How can we teach children to be creative, innovative, and better thinkers so that they can become productive members of society?" Creativity and innovation have also become strategic issues as organizations strive to remain competitive. Business leaders are asking the question: "How can we teach our people to be creative and innovative?"

As a result, K-12 schools, colleges, and universities have taken interest in creativity and innovation education. The disciplines of creativity and innovation are not well understood, however. Many people believe that creative or innovative thinking is the result of luck or chance. Others believe that inventive solutions are developed by people who are gifted in some special way.

Some methodologies for improving innovative thinking have been offered. Those who believe that group dynamics are important to the innovation process advocate methods such as synectics or brainstorming. Others advocate working on an idea, allowing time for incubation, and then waiting for inspiration. Still others believe in the Thomas Edison "trial and error" approach, which focuses on 1% inspiration and 99% perspiration.

The problem with relying on luck, genius, trial and error, etc., is that there is no reliable or repeatable method for teaching or achieving innovation. Therefore, improving productivity in the area of innovation becomes problematic [1].

Edward de Bono, the creator of lateral thinking, demonstrated that creativity is a skill that can be taught and developed by individuals [2]. De Bono developed many tools, including a curriculum for the direct teaching of thinking as a basic skill [3]. The curriculum has been used in over thirty countries.

While de Bono's work has gained some acceptance in the West, another distinctive approach to innovation, TRIZ, is relatively unknown. This is largely due to the fact that TRIZ (pronounced "treez") was not generally available to the West until the 1990s. TRIZ, The Theory of Inventive Problem Solving, provides a methodology by which people can systematically solve problems and enhance decision-making. Innovation by trial and error is replaced with a systematic approach [4,5]. The use of TRIZ also affects the neural networks in the brain, allowing people to become more creative and approach problems from different angles [6]. By applying TRIZ, "Organized ways of thinking replace the old chaotic ones"[7].

Evidence abounds that TRIZ methodology can be applied successfully by people of all ages, fueling optimism about the diffusion of TRIZ. Given the lack of knowledge about TRIZ in the West, however, curriculum development must accompany any effort to diffuse knowledge about TRIZ. This, in turn, will allow educational institutions to provide systematic instruction in TRIZ. Before addressing these educational issues, some historical background about TRIZ is provided below.

THE HISTORY OF TRIZ

TRIZ is an acronym for the Russian words Teoriya Resheniya Izobretatelskikh Zadatch, which, when translated, means Theory of the Solution of Inventive Problems [8,9]. Today, TRIZ is commonly used to refer to the Theory of Inventive Problem Solving, a slight variation of the literal translation.

Genrich Altshuller [10] is considered the founder of TRIZ. Altshuller began developing TRIZ in 1946, while employed in the patent department of the Soviet navy. Under Stalin's regime, Altshuller and colleagues studied tens of thousands of author's certificates (a type invention registration used in the Soviet Union) and patents (rarely granted in the Soviet Union) and discovered that principles of inventive thinking existed [11].

Altshuller was particularly interested in "inventive problems," which he defined as problems that had no known solution or problems for which the known or generally accepted solution created other problems. Educated as a mechanical engineer, Altshuller noticed inventive problems could be codified, classified, and solved methodically, just like other engineering problems" [12]. Altshuller sought to extract knowledge from inventions, compile that knowledge in usable form, and make the knowledge available to inventors in any area or discipline [13]. By identifying and categorizing the patterns in innovative solutions, Altshuller realized that one could gain access to solutions that would normally be "unavailable" due to one's specialization or narrow field of vision. The ideal system would allow inventors to match their problems to similar standard problems, which would lead to sets of potential standard solutions. Altshuller [14] wanted results that were not dependent on personal creativity or psychological techniques, like brainstorming.

While analyzing patents, Altshuller noticed that the same contradiction had been addressed in unrelated industries. Perhaps even more intriguing (and disturbing) was the time gap between the applications. Similar solutions were years apart. Altshuller realized the time gap was unnecessary; had the solutions been "accessible" to inventors, the solutions would have been applied much earlier to other areas. For example, the same process (gradually increase the pressure, then suddenly drop the pressure) is used in sweet pepper canning, shelling cedar nuts, shelling sunflower seeds, producing powder sugar, cleaning filters, and splitting imperfect diamond crystals [15]. While the process in each case is conceptually similar, the date of innovation is not. For example, there is an eighteen-year gap between the 1968 patent for pepper canning patent and the 1986 patent for cedar nut shelling [16].

The combined discovery that there were both regularities in design evolution and principles used in innovative solutions sparked a revolution in the field of inventive problem solving [17]. In a 1948 letter to Stalin, Altshuller and his boyhood friend, Raphael Shapiro, shared their discovery and voiced concerns about future inventions in the Soviet Union [18,19]. Their views were not well received; they were interrogated and tortured, then sentenced to twenty-five years in a prison camp above the Artic Circle [20,21]. This proved to be a sort of blessing in disguise, as the camp contained professors, scientists, etc. In 1954, about a year after Stalin's death, Altshuller and Shaprio were released, which allowed them to publish their first article in 1956; Shapiro published the first book on TRIZ in 1961, but later lost interest in furthering the dissemination of TRIZ [22]. Over the next few decades, professionals applied TRIZ to multiple disciplines, and the methodology improved.

Because of resistance by the State Committee of Inventive Affairs and the Society of Inventors (Altshuller was an intellectual Jew), Altshuller went underground, writing science fiction stories under the pen name H. Altov. In the 1970s, Altshuller's books and articles were finally translated and circulated in Germany and Poland, and eventually reached Japan and the West [23]. By the 1980s, Altshuller estimated that close to 100 TRIZ institutes had been established [24]. TRIZ flourished after perestroika. By 1985, Altshuller had written over 14 books, which constitute the collection of ideas and principles now known as Classical TRIZ, which include ARIZ (the Algorithm for Inventive Problem Solving) and Substance-Field analysis. The breakup of the Soviet Union provided many challenges and opportunities. Many TRIZ experts left Eastern Europe when North American businesses expressed an interest in applying TRIZ to their problems.

BASIC PREMISES OF CLASSICAL TRIZ

Many traditional approaches to creativity and innovation have a fatal flaw: as the complexity of the problem increases, the efficiency and effectiveness of the method decreases. For example, while all innovation requires some elements of trial and error, relying on trial and error to solve complex problems is terribly inefficient, since the number of trials can be astronomical [25,26]. Furthermore, trial and error provides no guarantee of a solution, since the trials may be conducted using the wrong variants [27]. Altshuller was particularly interested in reducing the time required to produce an invention and developing a structured, repeatable process to enhance breakthrough thinking [28].

Altshuller identified three basic premises of TRIZ: ideality, contradictions, and systems approach. More specifically, “1) the ideal design is a goal, 2) contradictions help solve problems, and 3) the innovative process can be structured systematically” [29]. While systematic innovation may seem like an oxymoron, TRIZ is built on the “realization that contradictions can be methodically resolved through application of innovative solutions” [30]. The following section of this paper focuses only on the first premise of Classical TRIZ, ideality. Future papers will address the larger body of TRIZ, which is continually evolving.

IDEALITY

When approaching any problem, there are two possible points of view. The first is aimed at improving the current undesired situation by asking: “How can we improve the current situation or process?” The second point of view starts from a vision of ideality and asks: “What is the ideal solution?” The distinction is critical, since each point of view leads one down a different path and toward different sets of possible solutions [31]. TRIZ attacks problems from the second point of view.

All systems have useful effects and harmful effects. Anything of value created by the system’s functioning is a useful effect. The domain of harmful effects can be equally large (the system’s costs, the space it uses, the fuel it uses, the noise it makes, etc.). Altshuller defined ideality as the quotient of the sum of the system’s useful effects (U_i) divided by the sum of the system’s harmful effects (H_j). Thus, ideality is expressed as:

$$\text{Ideality} = I = \frac{\sum U_i}{\sum H_j}$$

Altshuller noted that as systems evolve, they increase their degree of ideality. In other words, the sum of useful effects trend upward and the sum of harmful effects trend downward. Systems become more efficient and effective, although they rarely reach perfection. From this idea, Altshuller introduced the concept of the Ideal Final Result (IFR): the useful effects are great and the harmful effects are reduced to zero. In other words, in the ideal system, the function is performed without the existence of the system [32,33]. For example, the IFR for a machine is that the function of the machine is completed, but there is no machine [34,35]. Thus, in TRIZ nomenclature, ideality represents the state in which performing a desired function or effect occurs without the need for the system.

While it is quite rare to achieve ideality, using ideality as a goal is very effective at reducing psychological inertia. By defining the IFR, one is led in the direction of completely different solution paths [36]. Rather than concentrating on small, incremental improvements, one imagines the ideal state in which the desired function occurs, but the problem is absent. Traditional problem solving involves compromises and trade-offs, but ideality pursues solutions that eliminate the need to compromise [37,38]. For example, traditional problem solving might lead to compromise that increases the ideality ratio by increasing both useful and harmful effects. The increase in the useful effect (numerator) would merely be larger than the increase in the harmful effect (denominator). Alternatively, similar results could be achieved by decreasing the harmful effect (denominator) by more than the decrease in the useful effect (numerator). In contrast, TRIZ improves the ideality ratio by increasing the useful effect (numerator) while simultaneously decreasing the harmful effect (denominator).

Terninko, Zusman, and Zlotin [39] outline six paths to improve ideality. These are presented below along with examples [see 40,41]:

- Exclude auxiliary functions. Examples: Painting without solvents is accomplished by using an electrostatic field to coat metal parts with powdered paint. The parts are heated and the powder melts. The German C11 automatic rifle uses cartridges that have no cases. The expensive brass case was eliminated.
- Exclude elements and delegate the functions of those system elements to resources. Example: The expensive transmission that drives the propeller blades on the tail of a helicopter can be eliminated by directing a stream of exhaust gas from the motor onto the main blades to stabilize the helicopter.
- Identify self-service. Example: See the Container Destruction Problem case later in this paper.
- Replace elements, parts, or total system (use a model or copy). Examples: Airports simulate landing gear wheel traction using a test vehicle on the runway. Barbers in training can practice shaving balloons that are covered with shaving cream.
- Change or simplify the principle of operation. Example: To prevent sagging, hot sheets of glass are rolled on a pool of molten tin instead of a conveyor with rollers.
- Utilize resources (substances, fields, field properties, functional characteristics, or other attributes in the system). Examples: Exhaust pipes on trucks operating in deep open pits can be directed into the truck bed, allowing the coal, rock, etc., to filter out fumes. Snow can be blown into coalmines to cool the air and prevent explosions.

Since utilizing resources is at the heart of achieving ideality, the following section is devoted to that topic.

Resources

The key to achieving ideality in a structured and repeatable way is to identify resources already existing in the system that can be used to fix the problem. These resources can be used as is or combined to perform the function [42,43]. If the resources already exist, they do not have to be purchased. This means that the problem has been solved at no additional cost. Since cost is a harmful factor, the solution moves the system closer to becoming an ideal system.

An abundance of resources exists in most systems, and TRIZ practitioners are adept at identifying these resources. Many resources are things normally thought of as harmful side effects (e.g., vibration or heat). TRIZ practitioners examine whether they can convert these resources into something that can solve the problem. Other resources appear non-existent. For example, Terninko, Zusman, and Zlotin [44] point out that dead space is a resource used for temperature insulation (Thermo Pane windows) and sound insulation (sound baffles).

Ideality and Resources Case Study #1: Container Destruction Problem

The Container Destruction Problem is real world example widely used in the TRIZ literature [45,46,47,48,49] to illustrate how resources can be used to move a system towards ideality. This case involves a company that tests the resistance of a metal alloy to an acid environment. The metal alloy specimen is placed in a container filled with acid. After some time, the container is emptied and the specimen is inspected to determine what effects the acid had on the specimen. Unfortunately, the acid also damages the walls of the container, corrupting and invalidating the test results.

The case becomes more complex if one assumes the company performs tests for thousands of customers and has laboratory space filled with thousands of testing containers. The company realizes that customers have been gradually increasing the resistance of the products they manufacture. To make matters worse, the customers have increased the specifications for the tests (stronger acids, length of time, etc.). Therefore, the problem will not go away. Typical non-TRIZ solutions are to use a container made of a different material or to coat the containers with a special material. Assume the cost of either proposed solution is prohibitive.

To define ideality in the Container Destruction Problem, one first identifies the system. The system that contains the degradation problem is the container. It holds the acid and the specimen. By definition, ideality consists of having the function performed (acid in contact with specimen) without the existence of the system (the container).

Ideality is often achieved by performing the function with existing resources. The obvious resources in this system include the container, the specimen, and the acid. According to ideality, the container should not exist, so the focus is directed at the other resources. Focusing on the specimen, additional resources can be identified (geometric resources include size, shape, volume, etc.). The acid has resources, too (fluidity, specific gravity, volume, etc.). The environment surrounding the specimen and acid contains resources such as gravity, temperature, humidity, etc.

TRIZ practitioners develop the ability to find resources inside the system that contains the problem and use these resources to solve the problem. Often they transform resources or recombine resources in new ways. In this case, gravity, the fluidity of the acid, and the shape of the specimen were combined to create a solution. By changing the shape of the specimen, it became the container for the acid.

As mentioned earlier, TRIZ emphasizes achieving ideality using a structured and repeatable method. The process must be teachable and transferable to be valuable [50]. Whether one can solve the Container Destruction Problem is not the issue. One must be able to produce inventive solutions (ideality) consistently. TRIZ provides the structured methodology for achieving that goal.

Perspectives on Ideality

Ideality has subsets, since it can be defined from many perspectives. The ideal cell phone would have different meanings to different parties (the designer, the manufacturer, the distributor, the user). Even the users might have different views of the ideal cell phone, depending on whether it was used at home, at the office, or while traveling. The Container Destruction Problem was approached from the testing company's point of view. The container manufacturer would have a different view regarding how to solve the problem. In summary, innovation can be driven from many different points of view [51].

Local Ideality

Since ideality involves solving problems with existing resources, the solution will differ based on the environment and location in which the problem is present. The manufacturer of cell phone batteries may have made a significant capital investment to generate profits. The manufacturer would focus on using existing resources to generate a solution. At the same time, one should not ignore higher-level forms of ideality, such as performing the cell phone's energy function without a battery. The Container Destruction Problem solution involved the ability (resource) to drill a hole in the specimen or have the specimens already delivered by customers in unique shapes. Understanding local ideality is critical. Ideality is achieved through resources, so local resources will be used to achieve local ideality [52].

Super-Effects

Super-effects are often achieved when one approaches a near ideal solution; the value-added outcome exceeds expectations. The Container Destruction Problem solution illustrates several possible super-effects: 1) the company may have freed up considerable lab space, since containers no longer need to be stored; 2) investment in containers was reduced to zero; and 3) costs associated with handling, storing, and cleaning containers were eliminated.

Derived Resources

Most resources fall into one or more categories: readily available resources, substance resources, and derived resources. Readily available resources can be used in their existing state. Substance resources include material from which the system and its environment are composed; any system that has not reached ideality has substance resources [53]. While some resources are easily identifiable in a system, other resources are hidden within these resources. The hidden resources are called derived resources, since they are derived from combining, transforming, concentrating, and/or intensifying readily available resources [54].

TRIZ experts develop the ability to identify, modify, and combine resources. By looking deep inside the system, TRIZ practitioners discover new opportunities. In the Container Destruction Problem, the specimen was a resource. As one drills down deeper, one realizes the specimen has shape. Going still deeper, the word shape reveals myriad resources, such as diameter, roundness, surface finish, and height [55]. TRIZ practitioners do not generate long lists of resources and derived resources, however. They learn to find the right combination of resources without creating an exhaustive list of resources and potential combinations.

Secondary Problems

Implementing a solution may present new problems (e.g., how to change the shape of the specimen). TRIZ classifies these as secondary problems. Most people abandon ideas because of secondary problems. This is a mistake, since secondary problems are usually much easier to solve than primary problems. Therefore, a solution should not be discarded because secondary problems surface. Secondary problems should be documented so that they can be addressed. In fact, the exact same TRIZ methodology is applied to secondary problems to eliminate them.

Ideality and Resources Case Study #2: Pharmaceutical Tablet Inspection Problem

The following case study [56] illustrates how ideality and resources were combined to solve another real world problem. A 100-year old pharmaceutical company determines the need to reduce labor costs associated with inspection of a high-volume product. The product is produced in tablet form. At the end of the production cycle, the tablets move up a vibratory bowl, are discharged from the bowl, and slide down an inclined plane onto a conveyor. Three people visually inspect the tablets. Tablets are evaluated as good or bad (chipped) before packaging. Chipped tablets are discarded into a trash can. The production operation has been optimized to the point where all 15 manufacturing stages prior to inspection are best in class. Only 1% of the tablets are damaged at each stage in production. The output is 100,000 tablets per shift. The damage occurs in all 15 stages in roughly equivalent amounts. The result is 15,000 defective tablets per shift, which is unacceptable for packaging purposes. Management has determined that further optimization of the production process is not an option. It is already best in class.

Engineering recommends two solutions. One is a computerized visual inspection system and separation system with a total cost of $225,000. The other is a state-of-the-art computer-controlled weighing and separating system that weighs tablets and compares each tablet with the expected weight of a non-defective tablet. The cost of this system is the same, although there is some concern that a second system would be needed due to productivity concerns. Management deems that neither solution is acceptable; it would be trading low-cost inspection for high-cost equipment and technicians. Management wants a solution that costs less than $1000.

For this case, ideality is defined as follows: the function (inspection and sorting of the tablets) should be performed without the existence of the system (the three inspectors). In other words, the tablet should inspect itself. The next step is identifying resources. Although thousands of resources could be found, the engineers have already identified the resources for a near ideal solution. The visual inspection system used wavelengths of light interacting with the tablet surface. The term “visual” contains other possibilities, such as surface condition, color, reflectivity, tint, shading, etc. The weighing system used weight, which can be defined as the force with which gravity pulls on an object in proportion to its mass. Note that both engineering solutions also focused on what was different between good and defective tablets and how that difference could be detected.

The solution involved creating interaction between defective tablets and the inclined plane. The tablets were rolled on their edge down the plane. The conveyor was moved to create a gap between the inclined plane and the conveyor. The non-defective tablets rolled faster and crossed the gap to the conveyor. The defective tablets had less velocity, so they fell into the trash can, which was positioned between the plane and the conveyor. Thus, the resources of gravitational pull, the inclined plane, the velocity of the rolling tablet, the length of the plane, etc., were all combined to create a near ideal solution.

OTHER FOUNDATIONAL ELEMENTS OF TRIZ

Due to space limitations, only a brief presentation of two TRIZ concepts, ideality and resources, was provided above. The reader must be advised that this paper does not present a working knowledge of TRIZ. The discussion above, at best, provides a mere glimpse at two foundational elements of the science of TRIZ. The reader is warned against forming conclusions about TRIZ solely on the basis of this paper.

TRIZ is a methodology utilizing numerous principles, tools, and other methods that are supplemented by a knowledge base. To assist the reader in learning more about TRIZ from other sources, a non-exhaustive list of other elements of TRIZ is provided below. Each of these elements has a philosophical and applied base that is essential to gaining a complete understanding of TRIZ.

- Laws of Technological System Evolution
- Lines of Technological System Evolution
- 40 Principles of Invention
- 76 Standard Inventive Solutions
- ARIZ (Algorithm of Inventive Problem Solving)
- Technical Contradictions (and methods for their resolution or transformation)
- Physical Contradictions (and methods for their resolution)
- Contradiction Matrix
- Su-Field Analysis (Substance-Field Analysis)
- Systems Thinking (subsystem, system, and supersystem levels of analysis)

DISCUSSION AND IMPLICATIONS FOR TRIZ EDUCATION

One can attempt to solve problems using only personal capabilities and personal knowledge. TRIZ recognizes, however, that applying a methodology and tools significantly leverages one’s personal capabilities and personal knowledge. Clarke notes that TRIZ provides “the tools to turn anyone with a reasonable amount of intelligence and a little desire into an inventive genius” [57].

Terninko, Zusman, and Zlotin [58] point out that once one embraces the TRIZ methodology, several changes in thinking occur: 1) tradeoffs and compromise are no longer acceptable, 2) everything becomes a resource for the inventive solution, 3) ideality becomes an expectation rather than a dream, and 4) contradictions will become not only acceptable but attractive. Furthermore, the more one uses TRIZ, the more one will integrate TRIZ methodology with other problem solving methodologies, enhancing their effectiveness. This means, for example, that people using lateral thinking will benefit from learning TRIZ.

At the same time, TRIZ is not designed to replace one's problem solving methods. No tool or method is appropriate for all problems. For simple problems, trial and error may be an appropriate problem-solving tool. When the situation is complex and an innovative method is required for systematically creating solutions, TRIZ will likely be the best tool.

Issues for Curriculum Development

Since TRIZ education and training are provided in many forms, there is a need to develop curriculum standards. The Education Committee of the Altshuller Institute (AI) is working with TRIZ instructors (educators, consultants, schools, and organizations) to establish minimal standards for TRIZ courses and curricula. The AI Education Committee proposes that courses be classified at three levels: beginner, intermediate, and advanced. Each level, in turn, must meet specific learning objectives. For more information about the scope and sequence of the learning objectives, see the AI website [59].

Any TRIZ curriculum should be designed to give people a working knowledge of TRIZ. The implication is clear: merely gaining conceptual knowledge about TRIZ is insufficient. To benefit from TRIZ, one must practice and apply TRIZ on a regular basis. Therefore, any solid TRIZ curriculum initiative must address the issues of practice and application as well as conceptual knowledge.

Imposing a "one size fits all" model to TRIZ education appears unwise, however. Mann [60] points out that TRIZ students fall into at least four different profiles. The first group decides, after some minimal level of training, that TRIZ is not for them. The second group simply embraces whatever TRIZ tool most closely fits the way they already work and think. The third group continues to learn new TRIZ tools over time. This group experiences success with one or more tools. Ironically, for this group, the motivation to learn more about TRIZ is related to the fact that the user's current set of TRIZ tools eventually fails to produce results; the user realizes the need for other TRIZ tools. The fourth group is "infected" with the TRIZ virus. These TRIZ zealots are motivated to learn as much about TRIZ as possible. Clearly, one challenge that lies ahead is developing curricula that meet the needs of different types of students.

Curriculum development goals can be advanced with or without the use of software. Many TRIZ instructors use software to facilitate the learning process. TRIZ software applications differ considerably, however. Some instructors use software to provide relatively simple tools and deliver information. Others rely on more sophisticated software to mask some of the complexities of TRIZ, with the goal of reducing the amount of practice and knowledge one needs to be effective using TRIZ.

Conversely, some instructors focus on teaching TRIZ without the aid of computers or software. For them, the choice is equally deliberate, based on pedagogical philosophy and experience. Regardless of one's position on the use of computers to deliver TRIZ instruction, it is clear that computers will provide opportunities to enhance future developments of TRIZ curriculum.

The fact that students of various ages have applied TRIZ successfully fuels optimism about the potential impact TRIZ can have on the U.S. education system. Advocates for curriculum development point to the need to provide systematic instruction to students. Ironically, one barrier to overcome with students is the notion that structure or methodology impedes creativity and innovation. De Bono [61] is quick to point out that all structures are not confining. Many structures (e.g., a ladder) are liberating since they allow people to do more with them than without them. Simply put, tools make tasks easier for people. Creativity and innovation tools, like TRIZ, are no different.

Integrating TRIZ into the Curriculum

Formal education needs to be part of the solution, rather than part of the problem [62]. Formal education overloads students with information (which alone does not make a person creative). As students acquire more education, they also quit believing in fairly tales, which are loaded with contradictions. Terninko, Zusman, and Zlotin [63] cite a 1912 study by Antwan Ribaut that found creativity peaked at age eighteen, then decreased over one's lifetime. They note that Altshuller's replication of Ribaut's study in the 1970s found the age to be fourteen. Finally, they cite Zlotin's 1980 study, which found that creativity reached its lifetime low at age twenty-one. Zlotin's study suggested that colleges and universities actually reduce creativity among students. Clearly, there is a need to integrate TRIZ (and other creative thinking tools) into the standard curriculum to address this problem.

Multiple entry points for integrating TRIZ into the curriculum exist. Obvious examples in higher education include engineering schools, business schools, and science programs. Engineering schools in North America are already beginning to embrace TRIZ, due to its impressive ability to deliver innovative solutions to technical problems. (See, for example, the mechanical engineering program at Wayne State University.) In the foreseeable future, TRIZ will be a required subject in engineering programs.

Diffusion to Business Schools. Business schools will follow engineering schools for several reasons. First, the success of TRIZ in engineering programs will stimulate interest at business schools. Second, some natural diffusion will occur, since many engineers pursue MBA degrees. These engineers will bring their existing knowledge of TRIZ to the business schools. Third, the science of TRIZ includes the evolution of future generations of systems. This knowledge is invaluable for developing business strategy, developing new products, and erecting patent fences. Fourth, while TRIZ was developed to solve technical problems, the application of TRIZ to the solution of non-technical problems is evolving at a rapid pace. For example, Mann and Domb [64] developed a fascinating list of existing business applications/practices and classified them in a way that mirrors Altshuller's 40 Inventive Principles. Ruchti and Livotov [65] developed a TRIZ-based system for resolving organizational issues in business and management. Hipple [66] illustrates how the separation principles, originally developed to resolve technical problems, can be applied to non-technical problems in organizations. In short, the capability to develop solutions to non-technical business problems will make TRIZ indispensable across the business curriculum.

Entrepreneurship provides perhaps the best entry point into the business school curriculum, since the benefits of TRIZ are realized immediately. Dissemination of TRIZ to the broader curriculum will follow, and Quinn's [67] Competing Values Framework (CVF) is uniquely suited for that task. The CVF acknowledges the existence of paradoxes and the co-existence of seemingly opposite demands on organizations and managers. While a description of the CVF is beyond the scope of this paper, some examples are presented below.

The Competing Values Framework. From an organizational effectiveness perspective, the CVF identifies Innovation/Adaptation as the conceptual opposite of Stability/Control. Improving organizational effectiveness by increasing the Innovation/Adaptation parameter will result in a decrease in the Stability/Control parameter. The organization's attempt to become more effective (approach ideality) results in a technical contradiction. The typical method for dealing with contradictions is compromise or trade-off. TRIZ resolves contradictions without compromise, however. The CVF also takes a unique approach; it recognizes that opposite parameters can co-exist; people only assume the parameters are mutually exclusive in a real system. In fact, the CVF is based on the belief that it is actually desirable to pursue opposing parameters simultaneously.

The CVF also identifies eight roles performed by effective managers or leaders; each role has a conceptual opposite. For example, the conceptual opposite of the Monitor Role is the Broker Role. The result is a technical contradiction. As the manager devotes more energy or attention to performing the Monitor Role, the manager moves away from performing the Broker Role. The manager's attempt to become more effective (approach ideality) results in a technical contradiction.

Physical contradictions are at the heart of the CVF. For example, an effective manager is a Broker and is not a Broker. Clearly, the separation principles can be used to resolve this physical contradiction. Finally, the CVF emphasizes the need for innovation and creativity; one of the eight roles, classified as the Innovator Role, is devoted to this end. In summary, the CVF provides a unique framework for integrating TRIZ into the overall business curriculum.

Decision Making. Ruchti and Livotov [68] argue that TRIZ-based thinking methods can improve both the efficiency and effectiveness of decision making in organizations. They note that, although sophisticated decision making tools and methodologies are used in many organizational areas (product development, supply chain management, production, etc.), many other managerial decisions are based largely on intuition and personal experience. TRIZ-based tools could offer managers access to systematic and powerful thinking tools that would assist them in making day-to-day decisions. While undergraduate and MBA programs should provide instruction in TRIZ, Executive Education programs should be strategic targets for diffusing knowledge about TRIZ. At the very least, executives need to be exposed to TRIZ, since they control the resources necessary to advance TRIZ instruction in their organizations.

Science Education. Potential application for TRIZ in the sciences is unlimited. TRIZ yields tremendous efficiencies in the sciences by systematically eliminating the majority of solution variants and providing completely new solutions paths for research. This promises to revolutionize the scientific method and accelerate scientific discoveries. TRIZ-educated students in physics, chemistry, biology, etc., will not only leverage their disciplinary knowledge, but also draw upon knowledge found in other disciplines.

The crucial task is to reach science instructors and educate them about TRIZ. This may prove to be difficult. Most science instruction is narrow in focus and scientific research is even narrower in focus. This is due to the belief that a high degree of specialization is required to advance each scientific sub-field. TRIZ has the potential to liberate both science instruction and scientific research by leveraging knowledge found across scientific disciplines and providing an entirely new methodology for solving problems.

K-12 Curriculum. The call to integrate TRIZ into the K-12 curriculum is as strong as the educational imperative in higher education. The need to teach students to think clearly has never been greater. (See [69] for a third-grade course that utilizes TRIZ.) The entry points and issues for integrating TRIZ into the K-12 curriculum are similar to those of higher education. Teaching science classes to middle school or high school students without giving them access to TRIZ is doing students a great disservice. Traditionally, acquiring knowledge in the sciences has been separate from the ability to apply scientific knowledge. While educators might deny that assertion, studies show repeatedly that students using TRIZ can apply scientific principles to develop solutions when their "book knowledge" of science has failed them [70,71]. TRIZ unequivocally leverages scientific knowledge and unlocks the power of science.

TRIZ has the capability to make science far more interesting to students. Because students systematically discover solutions that involve applications of scientific knowledge, they begin to see immediate value in the sciences. In an era in which student interest in science education is of concern, it is heartening to realize that TRIZ may prove to be an effective way to stimulate students' interest in the sciences.

The perceived need to develop entrepreneurial skills and attitudes among children in the United States is shared widely. In response, schools have introduced curricula designed to develop these skills and attitudes. The benefit of integrating TRIZ into such programs is self-evident. In Ames, IA, middle school students were exposed to TRIZ as a tool to advance entrepreneurial spirit with astounding results [72,73]. The program was designed to determine if there was a better way to teach young students to be inventive problem solvers and entrepreneurs. Previous attempts to improve students' problem solving had been modest. The results of the TRIZ-based program were dramatic.

Summary. TRIZ deserves to hold its own place in the curriculum. Ideally, if TRIZ were taught as a separate subject, it would be formally integrated into other areas of the curriculum. Even without formal integration, however, students instructed in TRIZ methodology will develop the ability to think differently.

Integrating TRIZ into the curriculum may take time, since curriculum development is both difficult and political. The greatest challenge facing TRIZ proponents is the natural resistance to change embedded in most organizational cultures. Furthermore, the cultures of educational institutions are among the most resistant to change. Organizational cultures that embrace and institutionalize change will be needed to integrate TRIZ into the curriculum successfully.

CONCLUSION

Today's society faces a world replete with complex problems begging for innovative solutions. A methodology is needed to address these 21st century problems. Today's businesses operate in an environment characterized by change and competitive pressures. This environment requires a problem solving methodology for systematically eliminating roadblocks to new business processes and new product development processes. To be of value, any such methodology must be reliable, repeatable and teachable. TRIZ meets these criteria.

Although TRIZ was originally applied to technical problem solving, it has evolved into a system for creative thinking and innovation appropriate for a multiplicity of applications. TRIZ has grown to include applications for education, business, social and political issues, as well as the sciences [74]. TRIZ even includes systematic methods for forecasting the future development of technologies, uncovering causes for disasters, and eliminating potential disasters. New applications are continually appearing in *The TRIZ Journal* [75].

Integrating TRIZ into the curriculum is an educational imperative. Due to the circumstances surrounding the historical development of TRIZ, however, only a limited number of people have a working knowledge of TRIZ. The number of people capable of providing instruction in TRIZ is even smaller. This presents a challenge for developing TRIZ curriculum and for systematically integrating TRIZ into mainstream education venues. Curriculum development and integration are critical, however, to the diffusion process.

While developing curriculum, educators must keep in mind that students vary considerably in terms of their desire to learn TRIZ. The curriculum must be designed to help students achieve success in the early stages of training. The degree to which students experience success is believed to be a critical factor in determining whether they will continue to expand their TRIZ knowledge base [76].

TRIZ practitioners and specialists continue to build upon Altshuller's work, further advancing the science of TRIZ. Creating a mechanism for diffusing these advancements provides yet another challenge. Organizations, such as the Altshuller Institute, can play a critical role in that diffusion process, serving as liaisons between TRIZ specialists and North American educational institutions. Computer technology may also aid the diffusion process and offer new opportunities for TRIZ instruction.

The challenge facing K-12 schools, colleges, and universities is leading the dissemination of knowledge about the science and practice of TRIZ. These institutions will need to make a deliberate effort to incorporate TRIZ into their curricula. They will be dependent on liaisons, however, who can bridge the gap between TRIZ specialists and educational institutions.

REFERENCES

[1] Clarke, D. W., 1997, *TRIZ: Through the Eyes of an American TRIZ Specialist*, Ideation International Inc., Southfield, MI.

[2] De Bono, E., 1992, *Serious Creativity*, Harper Business, New York, NY.

[3] De Bono, E., 1973, *CoRT Thinking Program*, APT/T, Des Moines, IA.

[4] Salamatov, Y., 1999, *TRIZ: The Right Solution at the Right Time,* Insytec B.V., The Netherlands.

[5] Savransky, S. D., 2000, *Engineering of Creativity*, CRC Press, Boca Raton, FL.

[6] Kaplan, S., 1996, *An Introduction to TRIZ: The Russian Theory of Inventive Problem Solving*, Ideation International, Inc., Southfield, MI.

[7] Altshuller, G., 1996, *And Suddenly the Inventor Appeared*, 2nd ed., Translated by Lev Shulak (Originally published under Altshuller' pen name, H. Altov), Technical Innovation Center, Inc., Worcester, ME, p. 160.

[8] Kaplan, S., 1996, *An Introduction to TRIZ: The Russian Theory of Inventive Problem Solving*, Ideation International, Inc., Southfield, MI.

[9] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ*, CRC Press, Boca Raton, FL.

[10] Altshuller, G. S., 1984, *Creativity as an Exact Science*, Translated by Anthony Williams, Gordon and Breach Science Publishers, New York, NY.

[11] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ,* CRC Press, Boca Raton, FL.

[12] Kaplan, S., 1996, *An Introduction to TRIZ: The Russian Theory of Inventive Problem Solving*, Ideation International, Inc., Southfield, MI, p. 1.

[13] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ,* CRC Press, Boca Raton, FL.

[14] Altshuller, G. S., 1984, *Creativity as an Exact Science*, Translated by Anthony Williams, Gordon and Breach Science Publishers, New York, NY.

[15] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ,* CRC Press, Boca Raton, FL.

[16] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ,* CRC Press, Boca Raton, FL.

[17] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ*, CRC Press, Boca Raton, FL.

[18] Altshuller, G., 1996, *And Suddenly the Inventor Appeared*, 2nd ed., Translated by Lev Shulak (Originally published under Altshuller' pen name, H. Altov), Technical Innovation Center, Inc., Worcester, ME.

[19] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ*, CRC Press, Boca Raton, FL.

[20] Altshuller, G., 1996, *And Suddenly the Inventor Appeared*, 2nd ed., Translated by Lev Shulak (Originally published under Altshuller' pen name, H. Altov), Technical Innovation Center, Inc., Worcester, ME.

[21] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ*, CRC Press, Boca Raton, FL.

[22] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ*, CRC Press, Boca Raton, FL.

[23] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ*, CRC Press, Boca Raton, FL.

[24] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ*, CRC Press, Boca Raton, FL.

[25] Salamatov, Y., 1999, *TRIZ: The Right Solution at the Right Time*, Insytec B.V., The Netherlands.

[26] Savransky, S. D., 2000, *Engineering of Creativity*, CRC Press, Boca Raton, FL.

[27] Altshuller, G. S., 1984, *Creativity as an Exact Science*, Translated by Anthony Williams, Gordon and Breach Science Publishers, New York, NY.

[28] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ*, CRC Press, Boca Raton, FL.

[29] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ*, CRC Press, Boca Raton, FL, p. 3.

[30] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ*, CRC Press, Boca Raton, FL, p. 3.

[31] Clarke, D. W., 1997, *TRIZ: Through the Eyes of an American TRIZ Specialist*, Ideation International Inc., Southfield, MI.

[32] Altshuller, G., 1996, *And Suddenly the Inventor Appeared*, 2nd ed., Translated by Lev Shulak (Originally published under Altshuller' pen name, H. Altov), Technical Innovation Center, Inc., Worcester, ME.

[33] Altshuller, G. S., 1984, *Creativity as an Exact Science*, Translated by Anthony Williams, Gordon and Breach Science Publishers, New York, NY.

[34] Altshuller, G., 1996, *And Suddenly the Inventor Appeared*, 2nd ed., Translated by Lev Shulak (Originally published under Altshuller' pen name, H. Altov), Technical Innovation Center, Inc., Worcester, ME.

[35] Kaplan, S., 1996, *An Introduction to TRIZ: The Russian Theory of Inventive Problem Solving*, Ideation International, Inc., Southfield, MI, p. 4.

[36] Salamatov, Y., 1999, *TRIZ: The Right Solution at the Right Time*, Insytec B.V., The Netherlands.

[37] *Tools of Classical TRIZ*, 1998, Ideation International, Inc., Southfield, MI.

[38] Savransky, S. D., 2000, *Engineering of Creativity*, CRC Press, Boca Raton, FL.

[39] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ*, CRC Press, Boca Raton, FL.

[40] *Innovation Workbench Software*, 2001, Ideation International, Inc., Southfield, MI.

[41] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ*, CRC Press, Boca Raton, FL.

[42] *Tools of Classical TRIZ*, 1998, Ideation International, Inc., Southfield, MI.

[43] Savransky, S. D., 2000, *Engineering of Creativity*, CRC Press, Boca Raton, FL.

[44] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ*, CRC Press, Boca Raton, FL.

[45] Altshuller, G., 1996, *And Suddenly the Inventor Appeared*, 2nd ed., Translated by Lev Shulak (Originally published under Altshuller' pen name, H. Altov), Technical Innovation Center, Inc., Worcester, ME.

[46] Altshuller, G. S., 1984, *Creativity as an Exact Science*, Translated by Anthony Williams, Gordon and Breach Science Publishers, New York, NY.

[47] Clarke, D. W., 1997, *TRIZ: Through the Eyes of an American TRIZ Specialist*, Ideation International, Inc., Southfield, MI.

[48] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ*, CRC Press, Boca Raton, FL.

[49] *Tools of Classical TRIZ*, 1998, Ideation International, Inc., Southfield, MI.

[50] Clarke, D. W., 1997, *TRIZ: Through the Eyes of an American TRIZ Specialist*, Ideation International, Inc., Southfield, MI.

[51] Clarke, D. W., 1997, *TRIZ: Through the Eyes of an American TRIZ Specialist*, Ideation International, Inc., Southfield, MI.

[52] Clarke, D. W., 1997, *TRIZ: Through the Eyes of an American TRIZ Specialist*, Ideation International, Inc., Southfield, MI.

[53] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ*, CRC Press, Boca Raton, FL.

[54] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ*, CRC Press, Boca Raton, FL.

[55] *Ideation/TRIZ Methodology: IWB Self-Sufficiency in Inventive Problem Solving*, 2001, Ideation International, Inc., Southfield, MI.

[56] *Ideation/TRIZ Methodology: IWB Self-Sufficiency in Inventive Problem Solving*, 2001, Ideation International, Inc., Southfield, MI.

[57] Clarke, D. W., 1997, *TRIZ: Through the Eyes of an American TRIZ Specialist*, Ideation International, Inc., Southfield, MI, p. 2.

[58] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ*, CRC Press, Boca Raton, FL.

[59] *Standards for TRIZ Courses Proposal*, n.d., Altshuller Institute for TRIZ Studies, Inc., Worcester, MA. <http://www.aitriz.org/>, (10 November 2001).

[60] Mann, D., 2002, "TRIZ for Everyone (Even Those Who Don't Want to Spend a Year Learning It)," *The TRIZ Journal*, (January Issue), <http://www.triz-journal.com/>, (7 January 2002).

[61] De Bono, E., 1992, *Serious Creativity*, Harper Business, New York, NY.

[62] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ*, CRC Press, Boca Raton, FL.

[63] Terninko, J., Zusman, A., and Zlotin B., 1998, *Systematic Innovation: An Introduction to TRIZ*, CRC Press, Boca Raton, FL.

[64] Mann, D., and Domb, E., 1999, "40 Inventive (Business) Principles with Examples," *The TRIZ Journal*, (September Issue), <http://www.triz-journal.com/>, (7 January 2002).

[65] Ruchti, B., and Livotov, P., 2001, "TRIZ-Based Innovation Principles and a Process for Problem Solving in Business and Management," *The TRIZ Journal*, (December Issue), <http://www.triz-journal.com/>, (7 January 2002).

[66] Hipple, J., 1999, "The Use of TRIZ Separation Principles to Resolve the Contradictions of Innovation Practices in Organizations," *The TRIZ Journal*, (August Issue), <http://www.triz-journal.com/>, (10 December 2001).

[67] Quinn, R. E., 1988, *Beyond Rational Management: Managing the Paradoxes and Competing Demands of High Performance*, Jossey-Bass, San Francisco, CA.

[68] Ruchti, B., and Livotov, P., 2001, "TRIZ-Based Innovation Principles and a Process for Problem Solving in Business and Management," *The TRIZ Journal*, (December Issue), <http://www.triz-journal.com/>, (7 January 2002).

[69] An English translation of N. V. Rubina's third grade Course of Creative Imagination Development, based on the use of TRIZ, is available at <http://www.osaka-gu.ac.jp/php/nakagawa/TRIZ/eTRIZ/electures/eRubinaCIDBook3-1/GuideBook3-1.html>, (7 January 2002).

[70] Altshuller, G., 1996, *And Suddenly the Inventor Appeared*, 2nd ed., Translated by Lev Shulak (Originally published under Altshuller' pen name, H. Altov), Technical Innovation Center, Inc., Worcester, ME.

[71] Altshuller, G. S., 1984, *Creativity as an Exact Science*, Translated by Anthony Williams, Gordon and Breach Science Publishers, New York, NY.

[72] *Entrepreneurs Grow on TRIZ* (videocassette), 2001, Ideation International, Inc., Southfield, MI.

[73] *Middle School Students in Iowa Break New Ground for TRIZ*, n.d., <http://www.ideationtriz.com/>, (10 October 2001).

[74] Kaplan, S., 1996, *An Introduction to TRIZ: The Russian Theory of Inventive Problem Solving*, Ideation International, Inc., Southfield, MI.

[75] *The TRIZ Journal* is available at <http://www.triz-journal.com/>, (1 October 2001).

[76] Mann, D., 2002, "TRIZ for Everyone (Even Those Who Don't Want to Spend a Year Learning It)," *The TRIZ Journal*, (January Issue), 28-35, <http://www.triz-journal.com/>, (7 January 2002).