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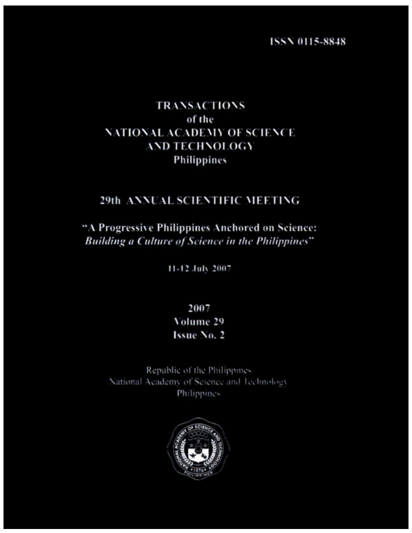

Teaching Innovative and Inventive Thinking: An Educational Imperative Towards Building a Culture of Science

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Teaching Innovative and Inventive Thinking: An Educational Imperative Towards Building a Culture of Science

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The pop culture on science, as popularized by the entertainment industry, shows that it deals with inventions. This culture, showing science as capable of outrageously inventing something whether good or bad, is etched in the consciousness of students. The preconceived notion developed by students is that when they study science, they too will be able to invent something. But how do we teach inventive thinking? The Philippine culture of complaining is reflective of the lack of proper training in problem solving skills, i.e. attacking a problem with the aim to be the first one to find the most viable solutions to the problem. This paper will tackle the promotion of improved problem solving skills among students towards innovativeness and inventiveness. The Theory of Inventive Problem Solving (TRIZ) is a powerful methodology for improving thinking processes, producing systematic innovation and creating novel inventions. The application of TRIZ has shown tremendous impact in the industry for decades (most new innovative products available in the market today are likely a product of TRIZ thinking). However, due to its developmental history which is tied to the industry, TRIZ is relatively unknown to educators especially in the Philippines. The potential of TRIZ principles and tools in developing innovative and inventive thinking among Filipinos is very promising and its applications have enormous benefits to society. This paper introduces TRIZ to Filipino educators and describes the initial attempt of integrating TRIZ in the academic setting. It also attempts to put creative and innovative ideas into inventive actions hoping to ignite the Philippine educational system thereby creating a culture of science.

Keywords: inventive thinking, innovation, TRIZ, science education

Introduction

The current curriculum in science teaching demands the integration of technology. Technology integration in science teaching does not only mean the use of technological tools in teaching, but the integration of technology like explaining the metal manufacturing process or showing the concepts in food production, etc. The technique also deals with explaining, in relation to the concept, how a certain technology works like a refrigerator, microwave oven, pressure cooker, etc. This requires that teachers are able to bridge the gap between the abstract concept and the practical applications.

Concept → Technological Application

The approaches in technology integration in science teaching are commendable in a sense that students get to see the relevance of the concepts being taught to real life situations. From an abstract model, the concept becomes real as can be seen by the wonders of the technology being integrated. However the essence of technology integration in this context is limited to appreciating the existing technology thereby promoting passive thinking among the students. There is a need to transform this practice to a more productive endeavor giving students the opportunity to solve problems, drawing on knowledge and skills from several disciplines and developing the capacity to apply knowledge and produce alternative solutions to real life problems.

In promoting a culture of science among students, this paper posits that science teaching should go beyond the mere integration of technology. Students should be able to sense that science and technology are continuously evolving and that they, as young as they are, can be a part of the next wave of concept that provides ultimate solutions to existing problems and improve the current state of technology or be the first to introduce the next level of technological application that will change the playing field.

Concept → Technological Application → Solves Problem via Innovation/ Invention

The learning process should therefore provide students the necessary tools, skills and opportunities so they are able to contribute to the body of scientific knowledge via inventions, innovations and ideas. Being able to do so can be promising, fulfilling and satisfying for students. This approach is anchored on Abraham Maslow's pedagogical model [1] that the highest level of learning is self actualization where students reach a level of extreme satisfaction via realization of self-development, as well as satisfying the esteem needs through recognition of their scientific contributions.

Developing a Nation of Problem Solvers

The Philippine culture of complaining is reflective of the lack of proper training in problem solving skills, i.e. attacking a problem with the aim to be the first one to find the most viable solutions to the problem with minimal costs and harmful effects. This is in contrast to the Japanese culture of aggressively finding solutions to even the most mundane problems like eating super hot noodles. Educators as well as government and business leaders are therefore asking the question: "How can we teach our people to be creative and innovative?"

The discipline of creativity and innovation however is not well understood. A well accepted notion is that creative and innovative thinking is the result of good luck or chance. Another school of thought is that inventive solutions are developed by people who are gifted in some special way. Educators who have taken interest in creativity and innovation education have offered methodologies like brainstorming through group dynamics. Others follow the "1%-inspiration-99%-perspiration" formula of Thomas Edison which calls for trial-and-error approach.

The trouble with luck, genius and trial/error approaches is that there is no reliable or repeatable method of teaching or achieving innovation. Contrary to popular belief, inventiveness, creativity and innovation can be taught and learned. Invention does not have to be an accident, and is not necessarily restricted to a few individuals with special talent. Invention and innovation are thought processes that can be studied, modeled, and reproduced — usable by all. Edward de Bono [2] demonstrated that creativity is a skill that can be taught and developed by individuals regardless of the race and he promotes direct teaching of thinking as a basic skill. While de Bono's psychological activation methods[1] are widely accepted, it is very beneficial to have innovation tools—tools that are readily available for people to innovate. A more distinctive approach to innovation called the Theory of Inventive Problem Solving (TRIZ) is available but relatively unknown (vide infra). TRIZ provides systematic method in solving problems and enhances decision-making.

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[1] *De Bono's methods include: Brainstorming, Lateral Thinking Methods, Six Thinking Hats, CoRT, etc.*

The application of TRIZ has shown tremendous impact in leading industries[2] for decades and its benefits to society is very promising. Most innovative products available in the market today are likely a product of TRIZ thinking[3]. However, due to its developmental history which is tied to the industry, TRIZ is relatively unknown to educators especially in the Philippines. It is with this perspective that the integration of TRIZ in Philippine academic setting is explored. By incorporating these inventive principles to science education curriculum, the problem solving capabilities of teachers and students will be developed towards innovativeness and inventiveness thereby developing a nation of problem solvers. This paper attempts to put creative and innovative ideas into inventive actions hoping to ignite, in the Philippine educational system, a culture of science and invention.

Teaching Innovative & Inventive Thinking through TRIZ

The current imperative of education is aptly echoed by Dr. Jim Killian, the former president of Massachusetts Institute of Technology, "The basic aim of education is not to accumulate knowledge, but rather to learn to think creatively, teach oneself and seek answers to questions as yet unexplored". But how do we teach creativity? How do we teach inventive

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[2]*Many Fortune 500 companies use TRIZ to design better products, simplify processes, understand disruptive market trends and improve their handling of intellectual property. Companies known to embrace TRIZ are: Siemens, Samsung, Delphi Automotive, LG, Christian Dior, Procter & Gamble, Dow Chemical, DuPont, BMW, Dutch State Mines (DSM), Motorola, Boeing, Kimberly Clark, ABB, Whirlpool, HP, Intel, Unilever, Colgate Palmolive , AMD, Chrysler, Daimler-Chrysler, Dura Automotive, Eastman Chemical, Ford, GM, Hitachi, Honeywell, IBM, Johnson & Johnson, Lockheed Martin, Kodak, McDonnell Douglas, NASA, National Semiconductor, Navistar Nortel, Otis Elevator, Panasonic, Parsons, Peugeot, Rockwell, Shell, Rohm & Haas, Rolls Royce, Teck Cominco, Toyota, TRW, UNISYS, United Technologies, Visteon, Xerox, etc.*

[3]*More companies are intensifying the TRIZ training of their personnel to strengthen their innovation capabilities. Engineers at Dow Chemical have developed new polymers with TRIZ. Otis Elevator used TRIZ to prevent escalator belts from wearing. Proctor & Gamble developed Crest Whitestrips™ and incorporated micro-motor inside the Crest SpinBrushTM using TRIZ. TRIZ solved automotive transmission problems at Peugeot. LG Electronics, eradicated noise problems in air conditioners using TRIZ. Despite success stories in industry, still little is known about TRIZ. These success stories would have attracted attention to the TRIZ methodology but due to the proprietary nature of the TRIZ projects in each company, these information are suppressed resulting to vast majority of people unaware of it.*

thinking?

Introducing TRIZ. The teaching of inventive skills can be achieved through a proven algorithmic approach called the Theory of Inventive Problem Solving or popularly known by its Russian acronym TRIZ (Teoriya Resheniya Izobretatelskikh Zadatch) [3, 4]. It started in 1950s when Genrich Altshuller, the founder of TRIZ, studied thousands of patents. Through patent analysis, he noticed that there are similar solutions for seemingly unrelated problems in different industries. Even intriguing is the existence of time gap between applications where similar solutions appeared years apart. For example, the generic concept of "increasing the pressure then suddenly dropping the pressure" has been shown to be applied in sweet pepper canning, shelling cedar nuts, shelling sunflower seeds, producing powder sugar, cleaning filters and splitting imperfect diamond crystals. While the inventive solution is conceptually similar, the date of innovation is years apart as shown in the 27-year gap between the patent for pepper canning (1968) and the patent for splitting imperfect diamonds (1995) [5]. This time gap could have been eliminated had the solutions been "accessible" to inventors.

Altshuller also noticed that inventive problems can be codified, classified and solved methodically. By identifying and categorizing the innovative solutions from these problems in patents, Altshuller realized that one could gain access to solutions that would normally be unavailable due to one's area of specialization or narrow field of vision. Hence he devised the 40 Inventive Principles by which most, if not all, problems can be solved. He also discovered that the evolution of a technical system is not a random process, but is governed by certain objective laws [5]. These laws can be used to consciously develop a system along its path of technical evolution.

How does TRIZ work? In TRIZ, the approach in problem solving is to raise the specific problem into a generic TRIZ problem (Figure 1)[4] which would lead one to sets of potential standard inventive solutions. Since the TRIZ inventive principles and general solutions are available, one can generate ideas easily (even outside one's area of expertise) reducing the time significantly. This approach is directional as opposed to the trial and error techniques where any attempts at solving the problem requires longer time, limited by one's area of specialization and may lead to more errors for every trial with more chances of problems not really solved.

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[4] *Figure 1 is adapted with modification from Souchkov, V. 1999. TRIZ: A Systematic Approach to Innovation Design < http://www.insytec.com/TRIZApproach.htm> (Accessed on 2007 June 4) and from TRIZ Basic Course Material, Intel Corp.*

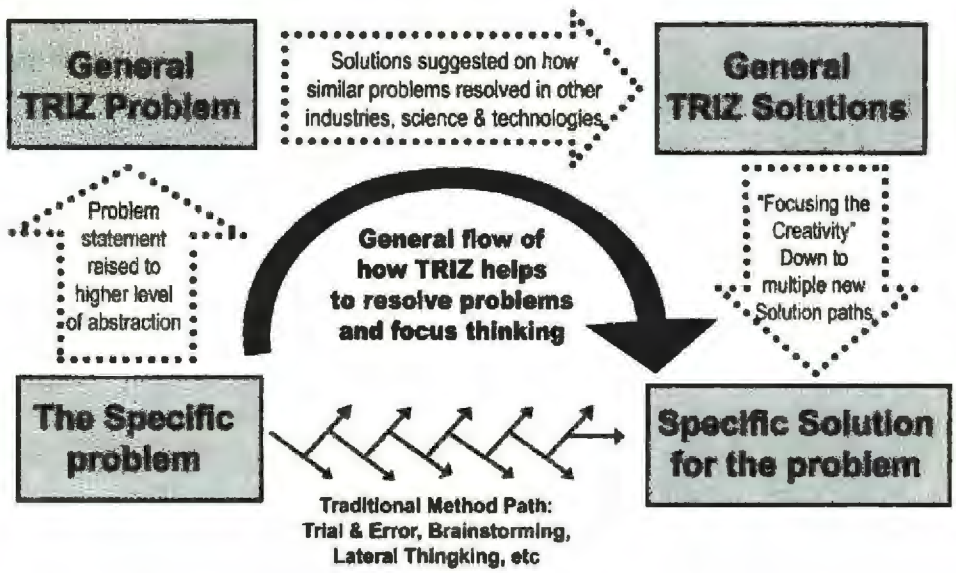

Figure 1. Directional path for solving problems in TRIZ as compared to traditional methods.

In raising the abstraction level of the specific problem, one needs to dissect the problem to the function level such that a functional model by which the problem occurs is built. Each technique in TRIZ consists of a number of guidelines, rules or principles which indicate how to cope with a specific problem or situation. Unlike the well known techniques for psychological activation, like brainstorming, TRIZ provides a systematic methodology for innovative solutions to a wide range of scientific, engineering, organizational or societal problems [6].

TRIZ Principles

TRIZ provides a set of principles that encourages people to think at a different level and to think outside-the-box. The following description of TRIZ is brief and is not meant to be comprehensive. Available books abound for complete description of principles.

Ideality Principle. When confronted with any problem, one is faced with two possible approaches. Clarke [7] aptly describes the two approaches: For any problem, one can look at improving the current undesired situation by asking: "How can we improve the current situation or process?" The second approach looks at a vision of ideality and asks: "What is the ideal solution?" The distinction is critical, since each point of view leads on different paths and toward different sets of possible solutions. TRIZ attacks problems from the second point of view.

"In the concept of ideality one imagines the Ideal Final Result (IFR) – the ideal state of the system where the desired function occurs but the problem is absent. Ideality is a qualitative representation of the ratio of the sum of a system's useful functions to the sum of its undesired factors or effects (Figure 2). It optimizes all the useful functions while eliminating all possible harmful effects including cost."[5] This is a result of Altshuller's discovery that all technological system evolves towards increasing ideality. Hence the objective of TRIZ is to strive for ideality but achieving it is very rare. Innovations nearing ideality are high level innovations. Using ideality as a goal is very effective in reducing psychological inertia[5].

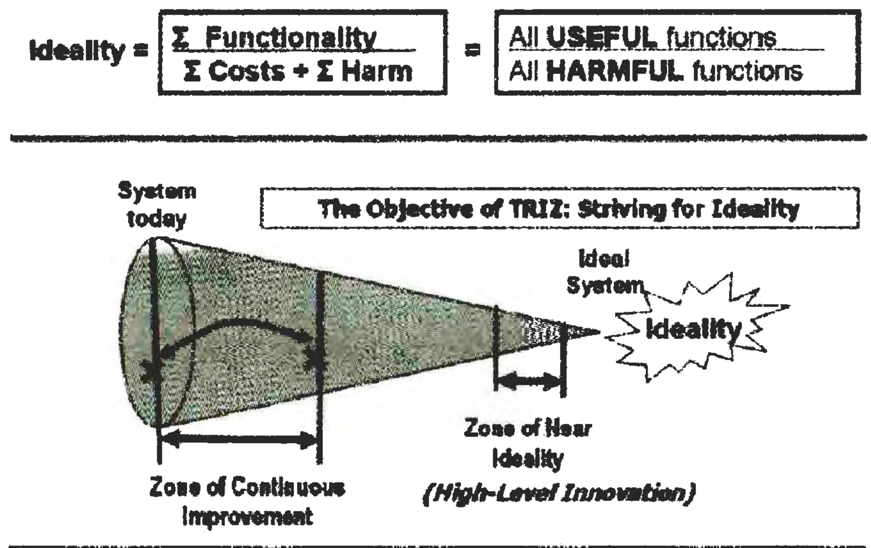

Figure 2. Ideality principle[6]

The ideal system performs a required function without actually existing. For example the IFR for a machine is that the function of the machine is

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[5]*Kowalick defines the psychological meaning of the word "inertia" as a state where one is indisposed to change due to human programming - a certain kind "stuck-ness" due to the way humans think. It represents the inevitability of behaving in a certain way because it has been indelibly inscribed somewhere in the brain. It also represents the impossibility, as long as a person is guided by his habits. Psychological Inertia (PI) represents the many barriers to personal creativity and problem-solving ability, barriers that have as their roots "the way that I am used to doing it." In solving a problem, it is the inner, automatic voice of PI whispering "You are not allowed to do that!" or, "Tradition demands that it be done this way!" Kowalick, J. 1998. Psychological Inertia. TRIZ Journal August 1998 < http://www.triz-journal.com/archives/1998/08/c/index.htm> (Accessed on 2007 June 4)*

[6]*Figure 2 is adapted with modification from TRIZ Basic Course Material, Intel Corp.*

achieved but there is no machine. The function is often performed using existing resources. These resources abound in any system. Some are free resources like gravity, wind, fluidity, shape, etc. Others are part of the system itself like the container, propeller. Other resources can be thought of as harmful side effects like vibration, heat. Some resources appear to be non existent like a dead space (which can be used for temperature insulation or sound insulation).[4] TRIZ practitioners are adept in identifying these resources and in converting these into something that can solve the problem.

To illustrate, a TRIZ classical problem [8] involves this scenario: "A metal's resistance to a strong acid is usually tested by immersing a cube shaped metal in the acid at certain temperature and time. The metal sample is then tested towards its effects on acid immersion. Unfortunately, the acid also damages the walls of the acid container, thereby complicating the test results. There is a need to improve the testing process especially if one is doing thousands of tests with limited acid containers. A typical solution provided by non-TRIZ practitioners worldwide suggests a change of the container into an acid resistant container or to coat the container with a special material. This type of solution is answering the question of: "How can we improve the current situation or process?" In TRIZ approach, one should ask: "What is the ideal solution?"

"Ideality is achieved by performing the function with existing resources. The obvious resources in this system include the acid container, the metal alloy, and the strong acid. According to ideality, the container is a harmful effect and should not exist, so the focus is directed at the other resources like the metal alloy itself, or additional resources can be identified (geometric resources include size, shape, and volume of the metal alloy). 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" [8].

TRIZ practitioners are skillful in finding resources in the system that contains the problem and use these resources to solve the problem. In this case, gravity, the fluidity of the acid, and the shape of the metal alloy were combined to create a solution: change the shape of the metal sample, such that it becomes the container for the acid. The solution is elegant in a way that it utilizes the available resources, eliminates the harmful effect (contamination with the corroded container is eliminated) and maximizes the function (to test the resistance of the metal alloy with acid). This kind of thinking is very innovative and inventive.

"TRIZ emphasizes achieving ideality using a structured and repeatable method. The process is teachable and transferable. Whether one can solve the problem is not the issue. One must be able to produce inventive solutions (ideality) consistently. TRIZ provides the structured methodology for realizing that goal" [8].

Contradiction Principle. The barriers to achieving Ideal Final Result comes in the forms of contradictions – a situation in which an attempt to improve one parameter of a system leads to the worsening of another parameter. In normal thinking, we often consider contradictions as a stumbling block to creative ideas. In TRIZ, one needs to search for the contradictions because by removing these contradictions in a system, a good inventive idea is generated. In fact, a very reliable indicator by which to evaluate an idea is to see if the function is maximized and it removes the contradiction.

To illustrate, this problem shows how contradiction principles helps solve a long standing problem in industry [9]: "In producing pure copper sheets, the electrolytic process generates a small amount of electrolyte liquid that is deposited on the pores on the surface of the sheets. When the copper sheets are stored the electrolyte liquid evaporates, creating oxide spots on the surface which reduces the value of the copper and results in financial losses. The best way to solve the problem was to avoid creating the pores in the first place. But doing so requires lowering the electrolytic current, which in turn results in significant reduction in productivity. Instead, a company usually decides to reduce the financial losses by washing the sheets of copper prior to storage to remove the electrolyte from the pores. This was not only costly but inadequate, and attempts at improving the washing process continued for long time. In fact for over 15 years (with millions in losses) engineers and scientists from similar productions all over the world tried to solve this problem. They achieved very limited success, mostly by pursuing better ways to wash off the electrolyte."

The contradiction in this problem is that the electrolytic current must be low to avoid pores, and must be high to increase productivity. By applying the methods in TRIZ for dealing with physical contradictions, a solution can be generated in a fairly straightforward manner. "To do this, one should ask the following: Where (if trying to resolve a contradiction in space) or when (for resolving a contradiction in time) do we really need the current to be low to avoid pores? The answer is obvious: a low current is needed at the end of the process to prevent the pores, while during most of the process the current can be high to ensure a high level of productivity. Given the fact that the complete cycle takes 72 hours, it was revealed that reducing the current for the last 30 minutes only was enough to produce pore-free copper. It is astonishing to note that with TRIZ training, people who have worked with the problem for 15 years were able to find the answer in half an hour!" [9].

Altshuller's researches revealed that inventors through the ages had been employing a relatively small set of techniques to resolve contradictions, regardless of the field or application in which they worked. From that, Altshuller identified 40 Inventive Principles. This collection of inventive principle is the most widely known and used in TRIZ problem solving technique where each principle recommends a certain method for solving a particular problem. If the problem can be mapped to a generic problem, then anyone can directly access the most used principles (which are systematically organized into a matrix according to the type of contradictions) and generate ideas to solve the problem.

Other Foundational Elements of TRIZ. Limitations in space only allow this paper to present very brief descriptions of two TRIZ concepts above. The reader must be advised that this paper does not present a comprehensive and working knowledge of TRIZ. The discussions presented merely provide a simple glimpse at two foundational elements of the science of TRIZ[7].

TRIZ is a methodology utilizing numerous principles, tools, and other methods. To learn more about TRIZ, a non-exhaustive list of other elements of TRIZ is presented below. Each of these elements has a philosophical and applied base that is essential to gaining a complete understanding of TRIZ.

- **Technical and Physical Contradictions**, a technique that helps problem solvers spot contradictions in a system and identifies methods for resolution.
- **Contradiction Matrix**, a tool that directs inventors on the statistically appropriate inventive principle in resolving a contradiction based on contradicting technical parameters
- **40 Inventive Principles**, a collection of inventive principles where each principle recommends a certain method for solving a particular problem.
- **ARIZ** (Algorithm of Inventive Problem Solving), an integrated technique aimed at solving most difficult inventive problems that contain physical contradictions.
- **Su-Field Analysis** (Substance-Field Analysis) is a method of analysis where the problem is modeled as two substances (two objects) that interact through a field. It helps to view a problem in different perspective such that different sets of inventive solutions are suggested.

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[7] *The reader is warned against forming conclusions about TRIZ solely on the basis of this paper. The author strongly recommends the references listed on the last part of this paper for a more comprehensive and detailed discussion with case studies to see the full merits of TRIZ.*

- **76 Standard Inventive Solutions**, a problem solving technique in TRIZ showing a collection of inventive standards for problems that involves undesired interactions.
- **Laws and Trends of Technology Evolution**. This involves the study and analysis of general tends in technology evolution and how one can get inventive ideas by predicting the changes the product will experience in the future basing from a general trend making it easier for anybody to develop a strategic plan for new inventions.
- **Systems Thinking**, a TRIZ technique that helps one to expand the vision and helps extend analysis level by looking at the subsystem, system, and supersystem
- **Scientific and Physical Effects**. This part of TRIZ focuses on studying how to use the knowledge of natural sciences (physics, chemistry, geometry etc.) in the inventive process.

Integrating Triz in the Academe

Integrating TRIZ into the academic curriculum is an educational imperative that must be addressed with urgency to develop among our people innovative and inventive thinking. As with most technical topics, TRIZ can be self-taught, but formal training helps focus the mind. TRIZ has been incorporated in most Russian schools including elementary level [10] and picked-up recently by American [11], European and Japanese schools [12]. Due to its impressive ability to deliver innovative solutions to technical problems, engineering schools in the US are already beginning to embrace TRIZ. In the foreseeable future, TRIZ will be a required subject in engineering programs. The potential of TRIZ principles and tools in developing innovative and inventive thinking among Filipino students is very promising and it is time we integrate TRIZ in our curriculum.

Science Education. The 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 utilize 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.

Initial Focus on Pre-service Science Teachers. The integration of TRIZ in the Philippine academic setting is explored initially in the existing pre-service science education courses at Philippine Normal University - Manila (PNU). By incorporating these inventive principles to the pre-service science education curriculum, future teachers will be capable of propagating the skills and concepts to high school students via multiplier effect. Pre service science teachers are also the stage where their minds are more open to new ideas compared to in-service science teachers. They are far more accepting to new concepts, strategies and technologies because they are less disturbed by imposed boundaries, limitations and bureaucracies often experienced by teachers in the field.

The approach in teaching innovative and inventive thinking based on TRIZ is developed and applied to third year science education majors in chemistry (BSE Chemistry and BS Chemistry for Teachers -BSCT) and physics (BS Physics for Teachers -BSPT) at the PNU. The third year level of science education at PNU is characterized by majorship stage where students focus on the content study of major science as they prepare for the research stage, teaching techniques and off-campus practicum on the fourth and final year. Science education majors at PNU are major feeders of competent science teachers at the public and private secondary schools in the country. These future teachers will also be major players as research advisers in the high school level science investigative research like the Intel's International Science & Engineering Fair, DOST's SIBOL and the National Science Fair by the Association of Science Educators of the Philippines (ASEP). By introducing TRIZ to the pre-service science education curriculum, future teachers will be capable of propagating the creative concepts, inventive principles and innovative thinking skills to secondary students thereby developing a culture of science and invention among students. The next phases of this study will include a secondary level incorporation of TRIZ.

TRIZ Training. Introducing TRIZ to university syllabi (as well as in secondary level syllabi) however is not easy. Although creating a totally separate 3-unit credit course dedicated to TRIZ is ideal (can be an elective course but should be a mandatory subject in any engineering course), the reality in any academic syllabi is that curriculum are exceedingly overloaded and there's no more slots available to introduce and insert a challenging and comprehensive subject like TRIZ. Considering the limitations, the present study is opting on alternative modes of instructions.

In industry the best known method in teaching TRIZ to engineers requires 40 hours (1 week) of training for the basic level and followed by 40 hours for advanced level and another 160 hours (1 month) are allotted for more advanced level usually taught by internationally recognized TRIZ masters. In between the basic and advanced levels, engineers are required to solve a real problem in line with his work area or create a verifiable inventive idea emphasizing the use of TRIZ concepts and tools. Aside from the TRIZ study materials available outside the industry, in-house mentorship and virtual community of TRIZ users are available within the company to sustain the trainings and learnings of engineers.

In introducing TRIZ to the academe, an abridged training material is developed for this present study considering the level of students. A two day seminar workshop for basic TRIZ was conducted initially for 29 interested students (will be expanded in the future study). The timing of the seminar is scheduled two days prior the start of the semester. This is to create effective transformational learning to students since they are fresh from vacation eager to learn again and most importantly, they are not pre-occupied with the rigors of the formal academic requirements and pressures at the time of the training. The seminar is designed to be appealing to students so that it induces a "mental knot" in the learner stimulating them to a "higher level of consciousness" such that old way of thinking is broken and replaced with a significantly different approach thereby creating a desire to apply and use it.

In constructing a learning experience around TRIZ, the following key areas are emphasized during the two-day seminar workshop:

a) **Patents**: emphasizing that patents are one of the greatest sources of human creativity and how these were analyzed by TRIZ inventor to come up with inventive principles.

b) **Problem consciousness**: increasing the awareness that problems become problems only because we are naturally affected by "psychological inertia" limiting our ability to solve problems only on things we know and how TRIZ can help get around these mental barriers to come up with out-of-the-box ideas.

c) **Innovation awareness**: developing the understanding of inventive creativity levels and realizing the difference between an apparent solution and break through innovation and show how TRIZ can take students out of their thinking limitations thereby developing solutions which they thought could not have imagined.

d) **Case studies**: show good cases and examples of ideas generated by TRIZ and emphasize the power of TRIZ-based thinking in coming up with an elegant solution maximizing functionality while minimizing cost and harmful effects.

e) **TRIZ principles and tools**: introduce TRIZ theories in an appealing way to show that it works and that students can feel they can adopt it easily.

TRIZ training in industry is increasingly aided by computers, softwares and pay-per-view online sources. While these tools may improve significantly the productivity of engineers, it does not guarantee creation of totally novel ideas. Observations have shown that development of better designs, new products and innovative inventions within short time are equally possible without the use of computers. Considering the limitations in most academic settings, the incorporation of TRIZ in the academe utilizes computer-free learning and emphasizes concepts, although free websites are provided for students to explore and maximize the benefits of online invention idea generations.

The two-day TRIZ seminar workshop is sustained by modular tutorials, weekly readings on TRIZ concepts and analyses of case studies. In as much as TRIZ cannot be studied in any meaningful way unless it is applied to solving problems, a regular TRIZ problem challenge is designed and posted for students to practice their learning in solving real world problems in competitive fashion. Cash prizes and the chance to have their ideas be applied for patent are ultimate come-ons for the TRIZ Problem Challenge. A group-on-one follow-up is conducted regularly for the whole semester to guide students in creating more innovative solutions to a real world problem of their choice.

Student's Responses and Feedback. Prior the seminar-workshop, 100% of the student respondents (and college professors surveyed) haven't heard about TRIZ before, confirming the observation that most people are not aware of its existence. When asked whether they believed they are creative enough to be able to invent something that can change the world, 24.14% answered in the affirmative, 13.79% said NO, while most of them (62.07%) said they are not sure. This result is anticipated since the current thinking prior introduction to TRIZ is that creativity or innovativeness is related to genes or luck and most are not sure whether they have what it takes to be innovative. When the 7 respondents who believed they can invent something were asked, most of them said they can work hard given a chance to work on a problem indicating a trial-and-error way of thinking. All of these conceptions about creativity, innovativeness and inventiveness however were revolutionized after the TRIZ seminar (Figure 3). All of them realized that the principles and tools of TRIZ changed the way they perceived a problem and that by using it, everybody believed that it increases their ability to solve problems and given more exposure to it, most believed they can indeed innovate or invent something.

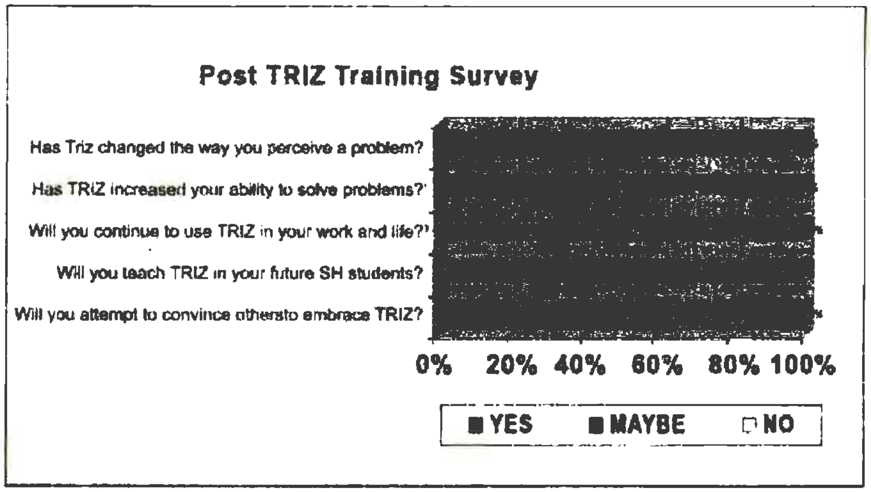

Figure 3: Post TRIZ training survey on science education students at PNU

The following are some of the comments given by the student respondents about TRIZ:

> *"With TRIZ it enlightened me that there are elegant solutions to all the problems we encounter and it provides us with strategies and organized way in analyzing the problem."*

> *"I used to see problems as a hindrance to achieving something but because of TRIZ I now see problems as a challenge - a chance to create something new to innovate and improve the way this world lives"*

> *"Using TRIZ methods as a guide to solve a problem, I can easily get a solution in a more innovative and inventive way. It helps me to think logically and see things in a deeper perspective."*

> *"Back then, I was used to solve problems without first analyzing its components thus I was consuming a lot of time thinking of a solution. Now, it's far more convenient to analyze every bit of components so as to use the right inventive principle. TRIZ has given me some techniques that I could use to help me hasten up my thinking capability in solving problems."*

> *"TRIZ made me think beyond my wildest imagination and I think that I can use these principles for life to make a difference for my country."*

When students were asked whether they will share the TRIZ concepts to friends and colleagues and teach it to future students, everybody was upbeat and answered optimistically. Below are some of their comments:

> *"I would truly want to share the concept of TRIZ to my students for this would help them in their studies and in their everyday life"*

> *"It is a big help for students especially in science so that they can start thinking innovative solutions to problems."*

> *"I will definitely share TRIZ, for who knows if one of my students would be the next great inventor."*

> *"TRIZ should be the best thing to be introduced to others knowing the importance and benefits one can get."*

> *"I want to share TRIZ because it would give many people the chance to exhaust their thoughts and the chance to widen their perspective in solving problems that they may encounter in life."*

> *"In teaching TRIZ, I will allot a session or two to introduce the basics of TRIZ and as application of lessons in chemistry, I will give a problem in real life situation and using TRIZ, they should provide solutions. I will also use TRIZ in advising investigatory projects for HS science fair. I will even incorporate TRIZ challenge problems in my authentic assessment tool and even recommend it with my co teachers."*

Team TRIZ Projects. Although third year students are not doing research subjects yet, TRIZ is helping them identify an interesting problem to work on. They were asked to give a generic real world problem that they would like to solve. Using the "ideality concept", "functional analysis tool" and "substance-field modeling", students are guided to dissect the problem into a functional problem such that inventive ideas can be generated using the TRIZ tools like the "contradiction principles and matrix", "trends in technology evolution", "scientific effects", etc. The following group projects are being worked on by some of the students:

Table 1: Sample inventive ideas generated by the students using TRIZ methodology[8]

General Problem	Functional Problem/ Contradiction/Trend	Inventive Principle/ technique used	Inventive ideas
Uncontrolled household pests	Increase of household cockroaches causes hygienic problems at home. If commercial anti pest sprays are used then the cockroaches will decrease but the spray effectivity will decrease after time.	Preliminary anti action Periodic action Nested Doll	1) Encapsulate the anti cockroach active ingredient such that it releases slowly over time. 2) Use the "nested doll" principle such that layers of layers of anti-cockroach active ingredients are hidden on a surface to where they are most attracted.
High % of biofuel blends cannot be used for old engines	If 20% biofuel blends is used, then the total fuel cost and consumption will decrease but the biofuel is incompatible with old engines due to filter issues.	Composite material	1) Design a composite material for the old engine filters such that the biofuel blend does not clog. 2) Use the concept of "increasing pressure then suddenly dropping the pressure" around the filter such that engine filters will be cleaned periodically.
Design of floor polishers is highly dependent on man	If floor polishers are to be ideal, it should be free from human dependency	Trends of technological evolution	1) Design a floor polisher similar to toy cars where it will bounce back once it hits a wall and put enough weight on the bottom so that it always returns to an upright position.

[8] *The ideas listed are potentially patentable ideas generated by the students. As a protection from possible copycats, the disclosure of these concepts here is a defensive publication which can be used as evidence of originality during patent litigation.*

During the exercise of idea generation for their team projects, students were encouraged to generate as much inventive ideas as possible, regardless of how silly and outrageous it may seem. A lot of concepts were easily generated with the aid of TRIZ tools and most are high level innovations. These concepts were trimmed down in terms of which are doable considering the time, the budget and the resources. TRIZ indeed was able to tap the innate creative ability that already exists within the students.

Summary

In today's challenging world, the necessity of improving the problem solving.skill among Filipinos is very eminent. An efficient problem solving methodology that is reliable, repeatable and teachable is therefore sought. TRIZ a system of creative thinking and innovation meets the criteria. The principles in TRIZ have been shown to be effective in creating innovative ideas in the industry for decades. Evidence abounds that TRIZ methodology can be applied successfully by people of all ages.

The potential of TRIZ to make science become more interesting to students is very promising. Since students systematically discover solutions that involve applications of scientific knowledge, they begin to see immediate value in the sciences. In this crucial time where the interest of students in science education is of immediate concern, it is heartening to realize that TRIZ may prove to be an effective way to stimulate students' interest in the sciences, and create a culture of science and invention.

Conclusion

Although no attempts were made to measure the individual creative and inventive characteristics of the students before and after TRIZ exposure, (this may be done in the future) the subjective observations indicate that the initial attempt at introducing TRIZ to students is successful and can very well be extended to any group of students including secondary and elementary pupils. When faced with a problem, it can be observed that the students were able to think about the problem in new ways, able to look for resources and aim for ideality in each solutions generated. It was also evident through sample problems and TRIZ challenges that the levels of inventive solutions are higher and that the time involved in solving a problem decreased.

Recommendations

It is necessary to teach our students innovative and inventive thinking and to integrate TRIZ into the curriculum if we are serious as a nation to improve our people, making them ready for the challenges that lie in the future. TRIZ is an educational imperative that must be addressed with urgency and it deserves to hold its own place in the academic curriculum. Teaching science classes to students without giving them access to TRIZ is doing students a great disservice. TRIZ is an important ingredient to education if we need to raise the level of the national "Creativity Quotient" of the Filipino people.

TRIZ training to in-service Filipino teachers is a first step. The TRIZ training of pre-service science education majors should be strengthened and institutionalized. The development of materials suited for Filipino students must be intensified such that incorporation of TRIZ principles to any secondary science courses can become comprehensive and lively. Integration strategies of TRIZ concepts to other areas of the sciences and field of studies need to be developed. Teachers must strive to make creative ways of presenting TRIZ principles to younger students. Large scale TRIZ challenges should also be implemented to sustain the learning of the students.

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Suggested Readings

The reader is directed to learn more about TRIZ Innovation Principles from the following sources:

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2) Altshuller, G. S., 1984. Creativity as an Exact Science, Translated by Anthony Williams, Gordon & Breach Science Publishers, New York, NY.

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5) Kaplan, S. 1996. An Introduction to TRIZ: The Russian Theory of Inventive Problem Solving, Ideation International, Inc. Southfield, MI.

6) Terninko, J., Zusman, A. and Slotin, B. 1998. Systematic Innovation: An Introduction to TRIZ, CRC Press, Boca Raton, FL.

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7) Souchkov, V. 1999. TRIZ A Systematic Approach to Innovative Design. <http://www.insytec.com/TRIZApproach.htm>

8) TRIZ Journal. < http://www.triz-journal.com/archives/year/>

9) Altshuller Institute for TRIZ studies. < http://www.aitriz.org/ai/index.php>

10) Ideation International. < http://www.ideationtriz.com/home.asp>

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

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[9] Zusman, A.; Zlotin, B. 2004. TRIZ Tutorial 3. <http://www.ideationtriz.com/TRIZ_tutorial_3.htm> (Accessed 2007 June 8)

[10] Atkins, R. **1998**. Creativity in a Russian Elementary School (An Interview with Tatiana Vassilevna Zakharov and Her Director). TRIZ Journal February 1998. < http://www.triz-journal.com/archives/1998/02/b/index.htm>. (Accessed on 2007, June 4)

[11] a) Rivin, E. I.; Fey, V. R. 1997. Use Of The Theory Of Inventive Problem Solving (TRIZ) In Design Curriculum. TRIZ Journal March 1997. <http://www.triz-journal.com/archives/1997/03 /b/index.html>. (Accessed 2007, June 4); b) Raviv, D. **1997**. Florida Atlantic University: Introduction to Inventive Problem Solving in Engineering EGN5040. TRIZ Journal March 1997. <http://www.triz-journal.com/archives/1997 /03/c/index.html>. (Accessed 2007, June 4); c) Clapp T. G. , Slocum, M. S. 1998. Theory of Inventive Problem Solving Pedagogy in Engineering Education, Part 1. TRIZ Journal Nov., 1998. <http://www.triz-journal.com/archives/1998/11/c/index.htm>. (Accessed on 2007, June 4)

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