Teaching Critical Thinking Skills in IT Using PINE-TRIZ

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ABSTRACT
TRIZ is a structured approach stimulating creative thinking and innovative problem solving. Corporations use TRIZ seminars and workshops to strengthen employees' critical thinking skills. This paper describes an ongoing effort at the University of South Carolina Spartanburg to use an extension of TRIZ, called PINE-TRIZ to develop conceptual, alternative, and analytical thinking skills in non-traditional information technology students. TRIZ expounds principles better suited for physical, chemical, and mechanical system. PINE-TRIZ builds on TRIZ by adding innovation principles applicable to information systems and information technology. If successful, we will have developed a way to teach critical skills to students who have historically found it difficult to perform in mathematics and science courses, where these skills have traditionally been honed, and will open information technology programs up to a much wider student base.

Categories and Subject Descriptors
K.3.2 [**Computer and Information Science Education**]: accreditation, computer science education, curriculum, information science education.

General Terms
Human Factors, Standardization.

Keywords
Critical thinking skills, lateral thinking, logical thinking, analytical thinking, IT curriculum design

1. INTRODUCTION
The Information Management and Systems (IMS) program at the University of South Carolina Spartanburg (USCS) is a 4-year, multidisciplinary, undergraduate information technology (IT) program terminating in a Bachelor of Arts degree. Formed just over three years ago, IMS has attracted a large number of transfers from other majors and traditionally not attracted to an IT program. These students are welcome to the program but present a problem because some are not as prepared as traditional IT students in mathematics, science, and technology. This is evidenced by poorer performance than their "traditional IT classmates" in certain subject areas. Specifically lacking are skills in conceptual thinking, logical thought, and analytical ability. IT programs have not had to teach these skills before, only hone them in mathematics, logic, and science classes, since the traditional IT student exhibits natural ability in these areas.

The non-traditional students in the IMS program historically have difficulty with mathematics and logic courses. So simply placing them in these courses is not the best answer. However, they do respond to, and do well in, other types of courses. Imperative for the IMS program at USCS, and for any IT program wishing to attract and retain non-traditional IT students, is to find methods of developing the requisite critical thinking skills without relying on the traditional subjects of mathematics and logic.

Because of the multidisciplinary nature of the IMS program, the IMS curriculum is cramped and it is not possible to simply add a course in critical thinking skills development. Instead, IMS is exploring ways to inject specially designed course material into existing courses. Exercises involving Altshuller's theory of innovative problem solving (TRIZ, pronounced "trees") require students to think conceptually, logically, and alternatively [1], [2], [3]. TRIZ teaches an algorithmic approach to innovation whereby certain parameters of a system are altered by systematically applying a set of innovation principles. Exploratory efforts injecting TRIZ exercises into existing courseware have proven promising. Students enjoy working the problems and respond well.

The TRIZ innovation principles are oriented toward physical, chemical, and mechanical systems, belying the origin of TRIZ. We at USCS have realized that some TRIZ principles do not apply to information systems and some principles applying to information systems are not included. We have been working to extend TRIZ by defining innovation principles for the information engineering domain. The extended TRIZ version is called PINE-TRIZ, for *permutative information engineering* TRIZ.

This paper introduces PINE-TRIZ principles and shows how IMS is using TRIZ and PINE-TRIZ problems to augment various existing IMS courses. The idea is that enhancing courseware with PINE-TRIZ will cause students to exercise and develop their critical thinking skills in applied areas of IT. We will see this reflected in improvement of the non-traditional students' performance.

2. TRIZ

In the 1940's, Altshuller and colleagues began studying some 200,000 patents analyzing the nature of innovation [1], [2], [3]. What has come from this analysis is a list of system parameters reflecting those things about a system that are usually changed by innovation and also a list of 40 innovation principles reflecting the way in which people usually innovate. This approach is now called TRIZ (pronounced "trees"), the Russian acronym for "theory of inventive problem solving."

Over the last decade, TRIZ has seen a significant rise in popularity. Many books and papers have been written about TRIZ and a sub-culture of seminars, workshops, and conferences has arisen around teaching TRIZ as an algorithmic way of creative and innovative thinking [4], [5], [6], [7]. The corporate world and academia are interested in TRIZ education because it facilitates creative thinking and innovative problem solving and many success stories have been reported [8], [9]. Figure 1 shows the 40 TRIZ innovation principles.

1. Segmentation
2. Extraction
3. Local Quality
4. Asymmetry
5. Consolidation
6. Universality
7. Nesting
8. Counterweight
9. Prior counteraction
10. Prior action
11. Cushion in advance
12. Equipotentiality
13. Do it in reverse
14. Spheroidality
15. Dynamicity
16. Partial or excessive action
17. Transition into new dimension
18. Mechanical Vibration
19. Periodic Action
20. Continuity of useful action
21. Rushing through
22. Convert harm into benefit
23. Feedback
24. Mediator
25. Self-service
26. Copying
27. Dispose
28. Replacement of Mechanical System
29. Pneumatic or hydraulic construction
30. Flexible films or thin membranes
31. Porous materials
32. Changing the color
33. Homogeneity
34. Rejecting and regenerating parts
35. Transformation properties
36. Phase transition
37. Thermal expansion
38. Accelerated oxidation
39. Inert Environment
40. Composite materials

Figure 1 – TRIZ identifies 40 principles on which innovation has been based in the past. This list is the result of examining over 200,000 patents and when used in a systematic way, facilitates an algorithmic approach to creative and innovative thinking.

One uses TRIZ to facilitate creative thinking in a structured way. For example, consider a production process in which an intricate part requires painting. The existing method of painting this part employs an automated robotic arm. However, the complexity of the part requires the robot arm to make many, precise movements and it is desired to come up with a different way to paint the part.

To apply TRIZ, one systematically attempts to apply each of the 40 principles of innovation to the problem at hand. By applying the *segmentation* principle (#1), one might think about decomposing the part into smaller parts and painting each separately before re-assembly. Applying the *prior action* principle (#10), one might refine the notion by painting sub-assemblies prior to initial assembly thereby avoiding the need to disassemble and reassemble the part. Using the "inversion" principle (#13), one might think of putting the part *in* the paint rather than putting the paint *on* the part and come up with the idea of dipping the part into a paint bath. A combination of the *segmentation, prior action,* and *phase transition* principles may stimulate the idea of powder-coating the intricate part.

Not all principles make sense given any particular context, and these are simply discarded. However, for any kind of problem one is likely to incur, application of at least one of the 40 TRIZ principles makes sense and assists in generating candidate alternative solutions.

Many corporations have reported that going through the structured, facilitated TRIZ methodology stimulates creative thinking, lateral thinking, and analytical thought and are using TRIZ to teach their employees to "think outside the box." Therefore, it follows that we should be able to use a TRIZ-like solution methodology in our IT coursework to stimulate development of critical thinking skills.

3. PINE-TRIZ

TRIZ practitioners have applied TRIZ to many different areas, including software engineering. One notices that some of the TRIZ principles apply only to mechanical and chemical systems while other principles could apply to both physical systems and software. [10], [11], and [12] list software engineering analogs to all 40 TRIZ principles.

However, information is fundamentally different than mass and energy. Some manipulations are possible with information that are not possible in physical systems. Altshuller based analysis on patents in the 1940's and 1950s—before the information age and before computers as we know them today were invented. Therefore, it is a natural consequence that the 40 TRIZ principles do not capture all innovation principles that are possible in the realm of information systems.

A continuing effort at USCS is to extend TRIZ to include information-specific innovation principles. As a project in progress final results are not available at this writing, however, Figure 2 shows the current list of PINE-TRIZ principles. The list starts with #41 to indicate that PINE-TRIZ is an extension of TRIZ.

PINE-TRIZ is an acronym standing for *permutative information engineering-TRIZ*. This name captures the way in which TRIZ principles are used. Practitioners usually start with a known system and then consider changing a part of that system, by applying one or more of the innovation principles, to create new candidate solutions (permutations). Since we are involved in IT, we choose to model those principles applicable to information engineering.

One applies the PINE-TRIZ principles the same way one applies TRIZ principles. As an example, consider ways in which a first-generation, catalog-based, automotive-parts commercial Web site could be overhauled. Applying the *metaphor* principle (#41), one might consider implementing an auction-based Web site rather than a catalog-based site (changing the metaphor). Using the *representation* principle (#42), one might replace a boring textual list of engine parts with an interactive graphical image of an engine with mouse-over and mouse-click actions leading to detail about in-stock inventory for a specific part. One might apply the *competition* principle (#45), by installing a live-chat bidding system pitting one potential buyer with another.

The concept of using PINE-TRIZ is the same as that for TRIZ—to assist in the generation of alternative solutions. It is expected that using PINE-TRIZ education and examples in the classroom setting will help develop critical thinking skills in students. In exploratory efforts, IMS students have responded well to having analytical problems placed in context. Since PINE-TRIZ is based in the information engineering domain, it is expected that such coursework will expose students to working on problems they are likely to encounter on the job.

41. Metaphor Utilize a comparative relationship between two unlike entities to leverage semantic similarities	Recycle Bin icon, Desktop
42. Representation (graphical/lexical) Change representation by using graphics instead of words to convey meaning (or vice-versa)	GUI vs. command-line interfaces
43. Semantics/Ontology Use different meaning contexts	Data labels
44. Scope Define boundaries of the system	Interfaces, legacy/new systems
45. Competition/Negotiation Establish an adversarial relationship in which each party attempts to maximize their own benefit	RFPs, auctions, bids
46. Complexity Increase or decrease the complexity of internal Interactions system or the interfaces to a system	Nonlinear dynamics, artificial life
47. Randomness Increase or decrease the amount of unpredictability	Artificial Life, digital DNA (mutations)
48. Emotional/Social Response Consider the societal impact of a system	Invasion of privacy
49. Cost Consider the expenditure of resources required to develop, maintain, and support a system	Total cost of ownership (TCO), return on investment (ROI), budget
50. Adoptability Gauge users' enthusiasm to accept/use a system	User advocacy, prototyping, spiral development model
51. Evolution Allow a system to improve by itself by producing variations that are culled by the application of some fitness metric	Digital DNA, genetic algorithms
52. Association Link pieces of information to form a novel structure	Hyperlinks, WWW
53. Generalize/Specialize Abstract away details to generalize and add details to specialize a model	Decomposition, taxonomies
54. Credibility Consider the credentials of a source of information	WebMD, news services
55. Temporality Alter the time-dependent nature of a system or the time-critical response	E-trade speed, download times
56. Privacy Protect information from illegal, undesired access, or unauthorized disclosure	Logins, inferential security measures
58. Manageability Enhance and facilitate controllability	Network mgmt.
59. Constraints Apply limits to parameters	Transaction time, throughput, space limitations
60. Usability Increase user-friendliness	Website navigation aids
61. Synchrony Match or mismatch production of information with consumption	Sync.transmission, async. Transactions
62. Reliability Modify the dependability, repeatability, and consistency of a system	Mean time to failure, uptime

Figure 2 – Additional innovation principles for the information engineering domain comprising PINE-TRIZ. These principles either do not appear in the original TRIZ list of 40 principles or apply only to information engineering and not physical systems.

4. DEVELOPING PINE-TRIZ MODULES

One of the four concentration areas in the IMS program is *education* and one course students take in this concentration is an instructional design course. This course teaches students how to create technology-intensive training and educational materials and often involve developing interactive and multimedia projects.

Students enrolled in this class in the fall 2004 semester will develop self-contained PINE-TRIZ training modules. The training modules will have several facets. One facet will be material designed for in-class delivery. These materials will be used during live lecture to introduce TRIZ, PINE-TRIZ, and guide the class in facilitated brainstorming activities using the 55 principles.

Another facet will be in-depth textbook material explaining both the software analogs to the existing TRIZ principles and the PINE-TRIZ principles. For the PINE-TRIZ principles, the motivation behind suggesting the principle will be given as well as numerous examples of applying the principle.

A third facet will be homework and test problems. These will be problem statements carefully designed to fit one or a few of the PINE-TRIZ principles along with candidate solutions expected to be derived by the student. This material will be used in giving and grading homework and exam questions.

Another part of the work to be done in the fall 2004 semester is to identify which existing IMS courses would best benefit from having the PINE-TRIZ material added. We will pick one or two courses to work with first and then expand to other courses based on results from this initial effort.

5. INTEGRATING PINE-TRIZ

To illustrate how we will integrate PINE-TRIZ into an existing course, consider the IMS 412 course involving local area networks. This course teaches basic networking technology such as the IEEE 802.3 standards, cabling, routers, hubs, and protocols. One portion of this course involves network design. Students are presented scenarios and are expected to apply the knowledge they have gained in class to arrive at an acceptable solution. The non-traditional IT students have difficulty breaking the problem down into parts and analyzing modifications to each part, then re-assembling the solution into a cohesive whole again. We believe this difficulty stems from the students' deficiency in critical thinking skills.

We will augment this section of the course by introducing selected PINE-TRIZ principles: *segmentation, extraction, asymmetry, consolidation, nesting, periodic action, cost, adoptability,* and *temporality*. Each principle will be explained in the context of network design and students will then be shown various scenarios which require changing some part of a network's architecture to achieve the goal. It will be demonstrated how applying the PINE-TRIZ principle results in the new solution.

An example of a specific network design problem involves a flat network topology whose resources are being monopolized by a relatively few number of network nodes. The better solution to this scenario involves isolating the problematic nodes from the rest of the network and providing duplicative connectivity to the set of problematic nodes while also retaining the shared connection to the rest of the network. Experience has shown that only those students with some real-world experience (working professionals) arrive at the total solution even though the concepts of routers, switches, hubs, bandwidth, and everything else that one needs to solve the problem are taught in the course. The non-traditional students do well when asked specific questions. The gap seems to exhibit itself when students are expected to apply specific knowledge in a conceptual way.

PINE-TRIZ will help stimulate the students' alternative thinking when working on this, and similar, problems because PINE-TRIZ gives the student a structured framework to work with. For example, the *segmentation* principle should lead the student to think about breaking up the network into pieces. The *extraction* principle should lead the student to think about "removing" the troublesome nodes from the network. This notion should lead to considering a router in network technology acting as a filter between the rest of the network and the problematic nodes. The *asymmetry* and *temporality* principles should stimulate the idea of unequally applying connectivity to the network to increase bandwidth, speed, and throughput to both segments.

By employing this teaching technique in multiple courses, students will learn how to think conceptually and analytically without realizing it. We expect this to not only improve in-class performance, but also to carry over into the students' professional lives and become a powerful methodology for them to exploit.

6. THE FUTURE OF PINE-TRIZ

This course of action is not without risks. After all, that is why it is research. We may discover students having more difficulty than expected in applying the PINE-TRIZ principles. This could lead to students being distracted from the primary course material and waste too much time learning PINE-TRIZ mechanics.

Another possibility is for students who normally would do well with the traditional style of teaching to respond negatively to this new approach. We will have to carefully construct the PINE-TRIZ courseware and embed in the traditional material so as not to compete with the course material. We will also remain flexible and let our experiences guide us. No one expects to be able to author the perfect PINE-TRIZ module the first time. We fully expect some trial and error and will report on such experiences in future papers.

We certainly expect our experiences in the fall 2004 semester to be successful. Once we have derived suitable PINE-TRIZ course material, we intend to conduct a controlled experiment designed to objectively measure the benefit of using PINE-TRIZ to enhance critical thinking skills of students. We intend to give a critical thinking skills test to all underclassmen in IMS, before they are exposed to PINE-TRIZ. We will then deliver the PINE-TRIZ material to some of the students in one or more courses and then re-test their critical thinking skills. We expect to see improvement across the board stemming from the students aging, and gaining more experience, but we will look for an improvement between the students exposed to PINE-TRIZ over those students not exposed to PINE-TRIZ. We will measure for this difference by looking both at the critical thinking tests and by tracking their grades in various IMS courses. Since one group will not be exposed to PINE-TRIZ, they will serve as the control group for the experiment. Research funding is being sought from state and federal sources to assist in this endeavor.

We recognize that the USCS IMS program is unique and what works here may not work for others. With this in mind, next year we will request that other IT programs around the country join us in experimenting with PINE-TRIZ. If we see success and acceptance in other programs, we will know that we have indeed developed a new way to teach critical thinking skills to non-traditional IT students. This would open IT programs up to a whole new demographic.

7. CALL TO ACTION

We would like to invite collaborators to join us in developing PINE-TRIZ. Please email the author with any ideas for additional principles of innovation in the information engineering domain. Also welcome are comments about the PINE-TRIZ principles listed in this paper.

We would also like to invite institutions interested in participating in next year's PINE-TRIZ study to contact the author by email.

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