Teaching Innovation-On-Demand in an Undergraduate Information Technology Program

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ABSTRACT

Innovative Problem Solving is a methodology for developing incremental improvements, or innovations, for any type of system. IPS represents a powerful critical and alternative thinking skill we wish to instill in every graduate of the Bachelor of Arts in Information Management & Systems program at the University of South Carolina Upstate. A new three credit hour course teaching IPS, called SIMS 307: Systematic Innovation, has been added as a required course at the sophomore level. Some of the course material was adapted from an existing professional training class historically taught to post-baccalaureate working professionals with an average age of 35. Adapting the course for students with an average age of 20, very little professional experience, and only one year of college education has required much effort. This paper describes IPS and some of the challenges overcome in designing and delivering the course.

Categories and Subject Descriptors

K.3.2 [**Computers and Education**]: Information Science Education – *pedagogy, course design.*

Keywords

Information technology, information management, innovation, teaching innovation, inventive problem solving, TRIZ, I-TRIZ, IPS.

1. INTRODUCTION

The Information Management & Systems (IM&S) program at the University of South Carolina Upstate (USC Upstate) is a Bachelor of Arts degree in applied multidisciplinary information technology (IT). Housed in the Department of Informatics, the curriculum comprises 120 credit hours and a unique mixture of subjects such as: computer technology, business, communication, and informatics. The program seeks to prepare professionals in the art and science of managing and exploiting information resources for maximal strategic advantage. Recently, a required course in *systematic innovation* (SIMS 307) was added to the IM&S curriculum teaching an inventive problem solving (IPS) methodology [1].

IPS is based on a specific analysis and modeling technique and the application of a knowledgebase containing innovative concepts, called *operators,* gleaned from the study of over two million patents. Using IPS, anyone can innovate about any type of system in any domain even if they do not consider themselves as being "creative" or "inventive."

We want our IM&S majors to be versatile problem solvers. Even though they are trained in IT, in the real world, graduates are involved in projects outside the IT domain itself. IPS gives these students a unique and portable problem solving skill set affording them the confidence to function as "outside the box" thinkers in any situation.

Historically, IPS has been taught to degree-holding working professionals with several years of professional experience in their field. A portion of the course material in the new course was derived from this professional-level training. However, at the sophomore level, students have just begun major coursework and are typically only in their second year beyond high school. As expected, teaching the IPS course material to inexperienced minds has presented several challenges. This paper first discusses IPS and its origins and then describes how the course has been fine tuned for delivery at the sophomore level.

2. TRIZ

TRIZ (pronounced "trees") is an acronym for the Russian phrase "Teoriya Resheniya Izobretatelskikh Zadatch" or "The Theory of Inventive Problem Solving" and dates back to 1946 when Russian engineer, scholar, and inventor Genrich Altshuller started reviewing patents looking for clues about how inventive people solve problems. Over the following four decades, TRIZ grew into nothing less than the science of technological evolution and the study of how to solve technical problems. This *classical era* of TRIZ saw the development of a number of tools and techniques designed to help practitioners inventively solve problems. However, TRIZ was largely unknown to the Western world until the 1980s when perestroika allowed some of Altshuller's work to be translated into English [2][3][4][5].

With the collapse of the Soviet Union, TRIZ scholars and colleagues moved to other parts of the world during the late 1980s and early 1990s. Some have continued to extend the art and the science of TRIZ. One group, based in the United Stated, has developed a modern extension called I-TRIZ (for "Ideation TRIZ") comprising four methodologies [6][7][8]:

IPS:	Inventive Problem Solving
AFD:	Anticipatory Failure Determination
IP:	Intellectual Property Protection
DE:	Directed Evolution

AFD is a way of analyzing potential failure modes of systems and devising ways to prevent them. DE is a method of “inventing the future” five to ten years ahead of the current state of the art. IP contains ways to secure the intellectual property rights potential competitors will need to compete with your inventions. IPS is described in detail below.

3. IPS

IPS is a generic methodology enabling practitioners to innovate on demand about any type of system. An innovation is an incremental improvement to an existing object or system. IPS seeks to expose the problem areas of a system and stimulate thinking about how to improve it. At the heart of IPS is a knowledgebase of over 400 *operators.* Each operator is an innovative concept gleaned from the study of over two million patents by TRIZ scholars. Using a structured system analysis and modeling technique, practitioners identify problem areas and match them with operators to stimulate creative thinking about ways to improve the system. Figure 1 shows the IPS methodology.

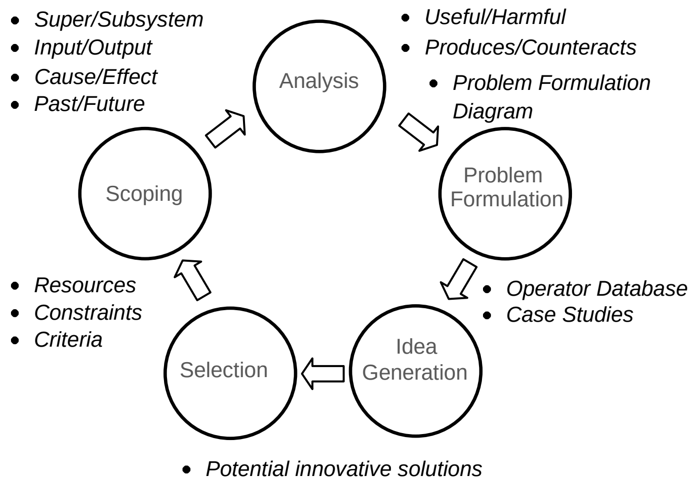

Figure 1. The IPS Methodology.

In the *scoping* phase, practitioners and subject matter experts identify resources, constraints, and solution selection criteria. With a systems analysis technique called the *8-way analysis,* practitioners create six abstract descriptions of the system, each from a different perspective: *supersystem/subsystem, input/output, cause/effect, past/future, useful/harmful,* and *produce/counteract relationships*. These descriptions are used to create a graphical representation of the problem domain known as the problem formulator (PF) diagram. The PF diagram captures the relationship between desirable and undesirable characteristics of the system and exposes areas of the system most likely to benefit from an innovation. By applying operators from the *operator knowledgebase* to different parts of the PF diagram, practitioners typically generate dozens of potential innovative solutions. A software tool called the Innovation Workbench (IWB) is used to develop the PF diagram and match operators with problem areas within the system.

To illustrate how operators stimulate creative thinking, consider the following two examples: “add a marker” and “preliminary action”

Add a marker

Add a marker that can become the source of an easily detected field.

Preliminary action

Consider completely or partially performing a needed activity in advance.

Adding radioactive dye to the bloodstream during an angiogram is one example of the add-a-marker concept. Partial demolition of a building in preparation for implosion is an example of the preliminary-action concept. These are just two of the innovative concepts in the operator knowledgebase. The theory behind IPS is that no matter what type of system is being studied one or more operators will be applicable and will likely stimulate a new idea.

Often, a combination of several operators helps form an innovative solution. For example, consider the containment ring problem in a jet engine. The containment ring is a thick and heavy metallic shield designed to prevent fragments from exiting the engine nacelle and damaging other parts of the aircraft in the event of a catastrophic failure of the turbine blades. However, the weight and bulkiness of the containment ring makes it difficult and expensive to perform the required periodic removal and testing. Dozens of potential solutions to this problem can be envisioned by applying various operators. For example, applying the operators:

- Segmentation
- Separation in time
- Separation on condition
- Introduce a liquid
- Add an intermediate layer
- Use a foam or empty space
- Abandon symmetry

suggests a solution involving non-uniform concentric ring arc segments containing a non-Newtonian impact gel and soft foam rubber forms as shown in Figure 2. For testing, the gel is drained and the segments removed and tested individually.

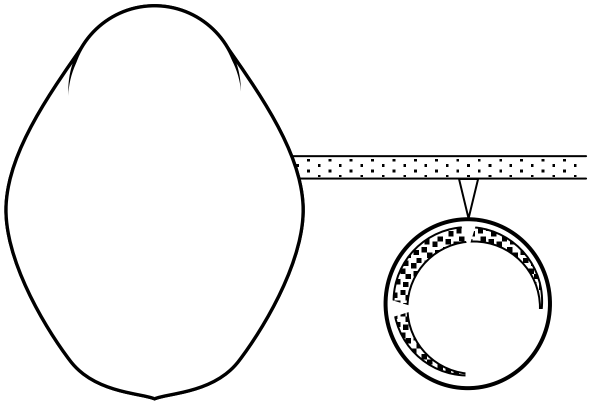

Figure 2. Innovative solution to the containment ring problem.

Each operator encapsulates an innovative idea employed in countless previous inventions and having this knowledgebase available is intended to:

- Help overcome psychological inertia
- View the problem in a different way

- Offer a solution containing an already solved problem
- Identify a resource needed to solve a problem
- Suggest an evolutionary step

However, the IPS knowledgebase in its entirety is overwhelming. Practitioners need a way to identify subsets of operators most likely to be beneficial to a given problem area. The PF diagram is a graphical modeling tool helping the practitioner to represent the system and problem domain in a way facilitating identification of relevant operators.

PF diagrams have a deceptively simple graphical vocabulary. IPS views systems as collections of *harmful functions* (undesirable features) and *useful functions* (desirable features). Useful and harmful functions are represented as nodes as shown in Figure 3.

Figure 3 – Useful and harmful functions in Problem Formulator diagrams

A function either produces (causes) or counteracts (inhibits) another function and these relationships are represented with arrows as shown in Figure 4.

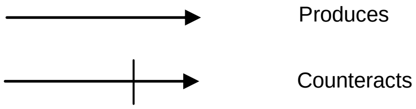

Figure 4 – "Produces" and "Counteracts" relationships in Problem Formulator diagrams

Sometimes, a useful function causes or enables another useful function which is a desirable occurrence. However, sometimes a useful function has undesirable side effects and causes something harmful to happen. In general, any two functions can be related in eight ways as shown in Figure 5.

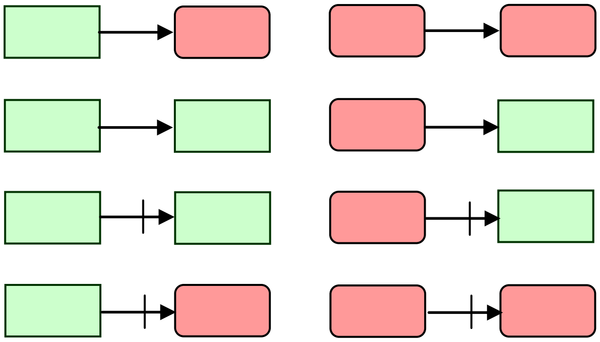

Figure 5 – Two functions can be related in eight ways

A diagram in the Problem Formulator is essentially a collection of produces/counteracts relationships between features and characteristics of the system. Any relationship that produces harm or counteracts good is an area of the system that can be improved. The goal of IPS is to stimulate ideas on how to overcome such unproductive relationships in the system. Doing so constitutes an innovative idea.

4. SIMS 307: Systematic Innovation

The systematic innovation course, SIMS 307, is designed to teach the IPS methodology to sophomore-level students enrolled in a multidisciplinary IT degree program, called Information Management & Systems (IM&S). The course is a 15-week course meeting twice per week for 1 hour 15 minutes each class meeting. The basic lesson plan for SIMS 307 is shown in Figure 6.

Week #1:	Intro, five levels of invention, containment ring example
Week #2:	The 8-way analysis, identifying useful/harmful functions
Week #3:	Translating PF diagrams to and from structured text
Week #4:	Exam 1
Week #5:	Drawing PF diagrams with the 5-step process
Week #6:	Intro to operators and operator organization
Week #7:	Extreme ranging and operator generalization
Week #8:	Exam 2
Week #9:	The Elimination/Alternative/Resolution strategy
Week #10:	Using the Resolution operators
Week #11:	Using the Elimination and Alternative operators
Week #12:	Exam 3
Week #13:	Student project presentations
Week #14:	Student project presentations
Week #15:	Final Exam

Figure 6 – Basic lesson plan for SIMS 307

For the required class project, students work on three or four-person teams each assigned a real-world problem. Some project topics include: a refrigerator that resists becoming cluttered, a safer golf cart, plowable roadway reflectors, a kite that is harder to get caught in a tree, an easy to remove pool cover, and a handicap-friendly and accessible electric vehicle mount for automobiles. During the execution of the project, students perform the entire IPS methodology and are tasked with identifying at least twenty potential improvements to the system.

5. Problems Encountered

The techniques in the IPS methodology can be taught to anyone in a matter of hours but expert-level performance requires time and experience. When first designing SIMS 307, it was expected that certain problems would be encountered since the course material was being derived from professional training intended for a more mature audience. A description of the traditional effort associated with designing a new course is not included in this paper. What is described here are the "surprises" encountered while teaching the new course to sophomore-level university students and the ways the course has been modified to overcome these challenges.

5.1 The History Problem

IPS, I-TRIZ, and TRIZ spans more than 65 years going back to just after World War II. Most of the history of TRIZ occurred behind the iron curtain within communist Soviet Union during the Cold War. In fact, Altshuller spent years in one of Stalin's gulags. The historical perspective and sociopolitical context of TRIZ adds richness and depth to the subject matter. When teaching working professionals thirty years and older, students understand the consequence without further explanation.

However, current college-age sophomores were born *after* the collapse of the Soviet Union and came though their middle school and high school education 15 years after the end of the Cold War. For them, this is all ancient history and not a history many of them are knowledgeable about. Many have never heard of the "iron curtain" nor have deep understanding of the Cold War and the cultural and political divide. Therefore, much of the import of the history of the IPS methodology is lost.

Accordingly, explanation has been added to several lectures in the course about communism, repression, censorship, the Cold War, the Stalinist regime, and the 1950-1980 political context. Of particular interest to students is the story of how and why Altshuller was imprisoned for a period of time for writing a letter suggesting ways for the communist government to be more innovative.

5.2 The Compartmentalization Problem

As is shown in Figure 1, the IPS methodology consists of several steps designed to evolve a structured collection of information. A practitioner is supposed to use one piece of information to help derive the next piece.

In SIMS 307, different steps in the methodology are embodied in a series of homework assignments. However, students tend to treat each assignment as a standalone piece of work and rarely carry information forward to the next assignment nor refer back to a previous assignment. This characteristic has also been observed in the student project work. The first final project reports looked like a collection of five or six separate pieces of work rather than an evolved and coherent body of work. Information appeared seemingly from nowhere in one part of the report and information in one part of the report was often never used anywhere else.

Explanation has been added to SIMS 307 stressing that words and phrases identified in earlier steps should be carried over to subsequent steps and explicit examples of this have been added to illustrate. In particular, part of a lecture is now devoted to showing a completed PF diagram and tracing several words and relationships in the diagram back to the intermediate step where they were first identified.

5.3 The Working Backwards Problem

In the first offering of SIMS 307, students were allowed to choose a system of their own as the subject for the class project. The rationale for this was that students might produce better results if they worked with something they knew and cared about. Using the IPS methodology, the student is supposed to analyze and model the system to expose the areas of need. Students are then supposed to systematically apply operators to the problem areas and document any innovative ideas stimulated by this process. Therefore, the solutions are supposed to evolve out of the IPS process.

However, almost every student who chose their own system *started* with an "invention" and then worked backwards through the IPS methodology. Their inventions were often good ideas but were of relatively low quality because they were not the product of the IPS structured analysis. There were telltale signs of this in the final project reports. First, there tended to be only one "solution" (i.e. the student's initial invention) identified in the project whereas typically at least two dozen different solutions are arrived at in an IPS project. Second, analytical results in the process tended to speak too directly to the student's solution and nothing else. Typically, the IPS process exposes many different areas of a system that could be improved. The students, by working backwards, sought only to document why their invention was justified. By doing the project in this manner, students missed dozens of potential solutions and also failed to recognize obvious and easy-to-implement solutions.

Currently, in SIMS 307, the students are assigned a problem by the instructor instead choosing their own. The problems are difficult with non-obvious solutions. At first, student reaction to the assigned problems is disbelief because they are systems students do not have any particular experience with. However, after some analysis, students have shown the ability of "getting their teeth into the problem" and performing the IPS methodology well.

5.4 The Modeling the Problem Problem

Steps in the IPS methodology are intended to give students several different ways to model the problem. At the outset, an overall goal is stated such as "make the golf cart safer," or "design a roadway reflector that can withstand a snow plow." Therefore, each step in the analysis is supposed to elaborate causes, effects, and relationships pertaining to this "primary problem." Students are also coached to "model the system and its environment." Often, inventive solutions involve modifying seemingly unrelated parts of the system or how the system interacts with the environment. Therefore, it is important to learn how to analyze and characterize the entire system.

It has been observed that students tend to forget to model the problem. Students seem to get caught up in modeling the system and environment and only as an afterthought "stick in" one or two things about the primary problem. For example, students' PF diagrams typically contain 30-50 functions and at least as many relationships for a total of about 100 elements. It is common to find less than 10% of the diagram referring to the primary problem. Failure to deeply analyze the primary problem, its causes, and the relationships surrounding it, cause students to fail to identify high-quality innovations.

Instruction has been added to SIMS 307 to stress the need to spend substantial amount of space in the PF diagram on the primary problem. Examples of inferior past student work are now shown during lectures along with corrections to the work with explanation as to what is expected.

5.5 The Conceptualization/Extension Problem

Each IPS operator encapsulates an innovative concept. Because operators were extracted from millions of patents, they are necessarily generalizations and sometimes represent high-level concepts. The lack of specifics in the language of the operators seems to cause some students difficulty in applying the operators. Juniors and seniors in the course, and working professionals seem to have much less trouble with the concepts.

Students must extend the concept encapsulated in the operator and "stretch" it sometimes to fit the problem at hand. For example, the *concentrate energy* operator, when taken literally, refers to the collection or focusing of some type of energy (heat, electricity, magnetism, etc.). However, the key concept in the operator is *concentration*. Many things other than energy can be concentrated. Students must learn to relax definitions of operators like *concentrate energy* to realize that concentrating flavor, emotion, political will, money, power, color, sound, feeling, sensation, etc. are equally important to consider. Most students miss such extensions of the concepts.

Lecture material has been added to SIMS 307 showing multiple examples of relaxing and extending the definition of several operators. Although students understand the examples in the lecture, work on the student projects still show limited flexibility in "turning a concept over in the mind." It may very well be that such flexibility can only come with maturity and experience. Under consideration is the addition of a homework assignment in relaxation, generalization, and extension, so this is an area still in progress.

5.6 The Extreme Ranging Problem

A useful mental technique when working with operators is to consider the application of an operator to the minimal and maximal extreme, a technique called *extreme ranging*. An easy example used in the current lecture materials is applying the *segmentation* operator to a boulder. Taken to the minimal extreme, the boulder could remain in one piece or just simply cut into two pieces. Applying the segmentation operator in increasing degrees toward the maximal extreme may result in a pile of gravel, then sand, then powder-like pulverized stone. The illustration is effective because there are such drastic differences in physical properties between a boulder and pulverized stone. Students have shown no problem in understanding this concept.

However, students show difficulty in using the extreme ranging technique in general. Students often do not apply the technique as effectively as they could. For example, the *remove substance* operator involves removing a component of a system. Applying the extreme ranging technique to this operator can have at least three different outcomes. First, we could consider removing anywhere from 0% - 100% of a particular substance. An example of this would be the removal of part of, or all, salt from sea water but leaving behind all other constituents. Second, we could consider removing anywhere from 0% - 100% of constituent substances. For example, we might envision removing carbon dioxide, carbon monoxide, and methane from atmospheric air but leaving other chemicals and elements. Third, we could consider partially removing something a part or object that is embedded. An example of this is illustrated by how opening a drawer partially pulls it out of a desk, but not completely. Students limit themselves when they do not consider all possible ways to extreme range an operator and results in overlooking entire classes of potential solutions.

Interestingly, it has been observed that when asked on an exam to define *extreme ranging* the majority of students failed to give the generic definition "the application of an operator to the minimal and maximal extreme." Instead, most students recited the boulder example from the lecture: "extreme ranging is like when you break something into only a few pieces or continue breaking the pieces over and over until it is pulverized." This is an effective description of extreme ranging when talking about the *segmentation* operator, but falls far short of the general description expected. Still, it shows that the students can identify the extreme ranging concept when they see it.

5.7 The Modeling the Solution Problem

The PF diagram is a graphical model of the system under study focusing on the primary problem being addressed. As such, the PF diagram is the result of the analysis evolved through the steps of the IPS methodology. On the student projects in the first offering of the course, students went through the IPS methodology, developed their PF diagrams, but then went back and inserted their chosen solution into the PF diagram.

Part of the reason for this was the "working backward" problem described earlier. Students were trying to document the justification for their solution. However, another reason students did this was confusion over the "secondary" and "tertiary" problem portion of the IPS methodology. As shown in Figure 1, the IPS methodology is depicted as a cycle. This is because any modification to a system causes side effects and changes the dynamics of other parts of the system presenting secondary problems to be solved. Coming up with modifications to overcome secondary problems causes tertiary problems, and so forth. Often, the key to an innovation is the successful solution to the secondary and tertiary problems. This was stressed in lectures in the first course offering possibly causing students to think they needed to "close the loop."

The iterative nature of the methodology is not stressed in current course lectures. Rather, we see this as best approached in an advanced innovation course possibly taught at the graduate level. Also, students are shown previous PF diagrams and explicitly instructed not to modify them to show the solutions.

5.8 The Grandiose Invention Problem

The IPS methodology teaches students to seek incremental, evolutionary improvements to a system. It has been observed that early in the course students think they must come up with a big revolutionary invention in order for the idea to count as an innovation. While there is nothing wrong in "thinking big," doing so exclusively causes students to miss more obvious, simpler, solutions. These are the solutions most likely to be implemented, so they should certainly be an outcome of the IPS process.

To stress this in lecture, a real-world case study was added to the course involving a solution developed for a major automobile manufacturer. The problem involved the rusting of a bracket attached to the fuel tank of a certain automobile model. The fact that it rusted was not a concern. In fact, the rust protected the metallic bracket. However, because of the design of the body of the automobile, the rusted part was visible to the owner when viewed from a certain angle. The company had spent much time and effort determining ways to rust-proof the part and had even considered redesigning the fuel tank. All such solutions were rejected as being too costly. One of the IPS-based solutions was to simply extend an existing piece of decorative plastic that was already part of the bumper assembly to hide the rusted bracket. This simple, rather, obvious solution was nearly cost-neutral to the company.

Also added to lectures are case study solutions in which the students are challenged to come up with a simpler solution. It has been shown that students naturally do well in this challenge and it drives home the point to look for the simple solution.

5.9 The Systematic Approach Problem

Being creative and innovative involves a careful balance of free-thinking, like an artist, and structured thinking, like an engineer. When considering operators, students are instructed to systematically work down a list of operators and with each operator, consider applying it to each word in the PF diagram, then each relationship, then consider extreme ranging the operator, then relaxing the operator and generalizing it to its highest level. This is a very effective mental technique but also is a rather sophisticated one. Students at the sophomore level seem to have difficulty in disciplining their thinking in this manner, especially when on their own working on the class projects. It has been observed that juniors and seniors as well as older students find this easier to do. So, it is likely that this is a function of student maturity and experience. Indeed, systematic, structured, yet far ranging and deep thinking is what college-level instruction is all about. Since SIMS 307 is one of the first courses IM&S majors encounter, we do not expect students to be well-versed in disciplined thinking. We hope, and we are starting to see signs of this, that exposure to SIMS 307 and these disciplined critical thinking skills make our sophomores better juniors and seniors.

6. CONCLUSION

We have successfully integrated a new course, SIMS 307: Systematic Innovation, teaching an innovative problem solving methodology into an information technology curriculum. We feel the methodology teaches valuable critical, lateral, and alternative thinking skills. It is still too early to tell if the course is making substantive and measurable impacts on students. A future paper will report on this matter.

We have adapted much of the course materials for the new course from an existing professional training course. We were aware at the outset of the effort there would be substantial changes made to adjust the delivery for college sophomores with only one year of college courses and very little professional experience. By and large, the new course has been well received and has been successful. However, there have been several surprises in the way sophomore-level students interpret the course material and approach the requisite work. This paper describes several of these challenges and describes modifications made to the course to overcome them.

The problems encountered seem to stem from the lack of professional maturity on the part of the students. This is in no way a surprise since they are just beginning their college careers when they take this course. We hope exposure to this course and the methodology not only teaches students a new skill but also serves to hone their professionalism.

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