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On the Efficiency of Teaching TRIZ: Experiences in a French Engineering School*

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Our industry is currently undergoing a transformation that is guiding it from the quality era to that of innovation. This transformation necessarily involves changing design practices, the foundations of which currently rest on an optimization mentality. An innovation oriented approach would require that the bases of the design action contain other rules of invention where creativity and problem solving would have priority. In order to address these requirements, some teaching institutions have initially resorted to teaching creativity methods by simply stimulating the ideation phases of standard design processes. Having reached the limit of what creativity methods could contribute; TRIZ appears as a likely alternative to such methods by providing greater structure and more results. However, the first experiments in teaching TRIZ rapidly revealed an incompatibility between the time needed for effectively using it and the time generally allotted for teaching a new method. This article presents the results of an experiment in introducing new TRIZ software and the way in which it was implemented in engineering students' coursework at INSA-Strasbourg over the past three years. These results lead us to state that the use of software improves quality in the TRIZ teaching process, especially with regard to the number of skills dealt with and acquired by engineering students in project situations.

Keywords: inventive design; TRIZ; innovation; teaching skills

1. Introduction: professional and educational background

Greater international economic competition bearing on industry has given rise to a specific requirement in the educational systems part of the labor market: acquiring inter-disciplinary skills that can be mobilized for use in professional situations [1]. The types of expertise sought include skills in communications, leadership, creativity and innovation [2]. What can engineering schools in France do to focus on this demand?

An analysis of the situation makes it plain that research and training in higher education should take into account and implement counterfactual reasoning and design [3]. Advanced professional training should concentrate on creativity and target people with high inventive potential in order to develop the creative, inventive and entrepreneurial capacities of a nation. Academics in French Grande écoles and the practice of benchmarking exclusively scholastic excellence hinder the implementation of university level design training programs that are based on creativity and inventiveness.

Didactic and pedagogic situations in French higher learning engage in training programs that are minimally transferable, overly theoretical and disciplinary, inadequately focused on developing capabilities for dealing with complex or vague issues, which use critical thinking and analysis of contradictory perspectives [4]. In contrast, learning inventiveness in an engineering school can never be exclusively theoretical, mono-disciplinary and non-transferable. An essential question emerges from these reflections: How should the pedagogic organization for learning inventiveness be structured?

Two teaching methods currently co-exist. The first, which is predominant in France, focuses on deductive reasoning and is based on a transference approach in education [5]. Lecture courses are given intended to engender ideas in the minds of students. These ideas are tested by means of evaluating exercises submitted during lab work. Practical coursework is used to set up a scenario and a simulation of professional activities to assess situations regarding concepts dealt with in lectures and in labs. The second pedagogic method, which is less widespread, develops inductive reasoning and mobilizes active teaching [6] during training sessions in the form of a project, where lectures, lab exercises and practical coursework have lesser importance, or are nearly absent.

The distinction between active and transmission teaching methods is less the nature of the educational relationship, be it active, participative or interactive, or the teaching type, with lectures, labs or practical coursework as opposed to a Project. More important is the status of knowledge retained and its relationship with inferred knowledge. The transmission method builds knowledge with an end in mind, where learning means acquiring knowledge

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and identifying with the model of a learned engineer. In contrast, active pedagogy considers knowledge a means of developing skills. Learning consists of accumulating knowledge that is inherent in expertise and behavioral knowledge. Transmission teaching methods are adapted to students that maintain a relationship to knowledge of a scientific nature, where the student learns in order to master intellectual knowledge. Active pedagogy is appreciated by students with a relationship to experiential knowledge, where students learn in order to master action-based knowledge.

This article postulates that learning inventiveness and creativity is aided by active pedagogy methods. This hypothesis is based on the features of pedagogy and of inventive learning [7]. Learning inventiveness is based on the capability of developing completely new situations. Developing situations like this mean understanding autonomy and having a critical outlook. The "knowledge" object, in the case of a transmission pedagogy, is much less subject to criticism than active pedagogy where knowledge is selected by the student, with some knowledge discarded after critical review and other knowledge considered pertinent for offering solutions. Being independent means creating one's own action maxims separately. While transmission type pedagogies allow little moving between individual and team work, active pedagogies teach students to move rapidly from an individualized knowledge production situation to a situation involving the presentation of knowledge, lines of argument for a project or defense of a position. This type of interaction provides the backdrop for establishing autonomy through an awareness of rules used by others.

Learning inventiveness marshals active pedagogy methods. In as much as higher education in France is primarily based on the country's traditional pedagogy methods, the situation is unsuited for new learning methods. This article presents a new IT-based resource that promotes transitioning to active teaching of inventive learning methods. Using a software program could thus allow more rapid learning of inventive methods and provide structure to the inventive process. The following case study illustrates progress in the area.

2. Case study: the CE5 Course module at INSA Strasbourg

What conditions lasting acceptance of new knowledge within an educational system is not so much the result of an institution-backed effort such as a national program, as recognition on a social level of the utility of new concepts by all persons concerned in the educational arena, including students, faculty, recruiters and parents. While this assumption refers to all knowledge, it is observed with greater acuity when new or innovative methods are introduced. As with economic innovation, pedagogic innovation is an activity involving risk. An educational staff must, within a limited period, demonstrate that the teaching makes sense. The following pedagogic experiment is in keeping with the same concept.

While some authors have investigated a parallel learning of both optimization and inventive methods [8], we have introduced a new method of teaching design that focuses exclusively on inventiveness. The reference theory for this method is TRIZ [9], the theory of Inventive problem solving (Altschuller). Others investigations have tried to simplify the teaching of TRIZ in using trimmed approaches [10] we decided not to make compromises on what is to be taught. In some researches, TRIZ has already been the focus of interest while not encompassing a software use [11, 12]. The coursework presented here consists of a mandatory module of 14 hours of lecture accommodating 70 students, and 14 hours of lab work, for a total of 28 hours of teaching in an environment that does not favor the active pedagogy method. This pilot program is being conducted in the mechanics department with three specialties: Mechatronics, Plastic Manufacturing and Engineering and Mechanical Engineering. The Mechanical Engineering section is split into Material and Structural Engineering, Industrial Engineering and Production Systems Engineering. In all, 70 engineering students in their final year are involved in the teaching experiment.

The method is being used during the entire first semester. The second semester involves no coursework and is devoted to completing final year projects. At this stage, students are assuming the responsibilities of a professional in management. Since our school trains engineers in design, the course takes on all of its importance prior to entry into professional life.

The course is given as follows: Two hours of lecture, followed by two hours of lab work and two additional hours of lecture. This "Theory—Practice—Theory—Practice" sequence provides the opportunity to rapidly implement knowledge acquired during lectures.

The overall teaching method is entitled "Design Execution 5", with the fifth module devoted to practical execution of a theory broken down into procedures. The objective is to go beyond a basic introduction to the TRIZ method by providing content that is sufficiently complete for the process to produce specific results that are not simply a

TRIZ overview. At this stage in young engineers' coursework, they have had several industrial encounters through internships as well as several design projects, so they have already built computer models of functional solutions. In other studies dedicated to freshmen [13] or first year students [14], the condictions were obviously different. Prerequisite results have therefore been sufficiently acceptable for them to move beyond simple abstract designs to produce explicit and credible models for technologically plausible solutions.

3. Basis for our experimentation

We used the backdrop and resources described in the preceding section to bring engineering students to a level of TRIZ understanding that will enable them to use it in their future industrial experiences. The teaching experiment was conducted over five consecutive academic years. During the first two years, lab work was done in teams without a dedicated software package. A software tool was provided during the last three years to support a study that included most of the milestone functionalities of lab work. This experimentation made it possible to clearly show the methodological gaps related to TRIZ from the perspective of a method for aiding in the design of innovative technical systems as it is highlighted in [15]. Use of the computer tool teaches independence and how to take the initiative, which is the leavening of active pedagogy. The following analysis of content is intended to determine whether the use of software for design instruction will promote active and inventive learning.

The following paragraphs follow the theoretical and practical routes as presented by function and by association with the TRIZ glossary.

Theory and practice: Section 1: Choose a subject, build a basic model and break down the model according to the TRIZ system completeness law, Law 1.

Theoretical Skills to be acquired (2 hours):

- TS1.1: Understand the limits of the classical approaches to design.
- TS1.2: Differentiate between Innovation, Invention and Ideas.
- TS1.3: Understand the historical aspects of the emergence of TRIZ-related work.
- CT1.4: Define a technical system by its triptych "Tool—Main Useful Function (MUF)—Object".
- TS1.5: Break down a technical system in accordance with the law of system completeness.

Practical Competence in Lab Work:

- For PC1.1: Ability to choose a subject judiciously and aptly for experimentation with TRIZ.
- For PC1.2: Find the most appropriate technical system for study from among existing versions of a given system.
- For PC1.3 (not evaluated in TD1): Provide a TRIZ-based definition and differentiate from among its axioms, tools, methods and knowledge meta-bases.
- For PC1.4: Using a technical system selected by the student, appropriately isolate the Tool, the MUF and the Object.
- For PC1.5: Using a technical system selected by the student, break down the tool into four components (Engine, Transmission, Work, Control) and its Energy input.

Theory and practice: Section 2: multi-screen scheme

Theoretical Skills to be acquired (2 hours):

- TS2.1: Understand the multi-screen presentation model.
- TS2.2: Cite and describe two essential functionalities and their added values in industrial use.

Practical Competence in Lab Work:

- PC2.1: Present the technical system chosen as well as its system and time-related variations in a multi-screen scheme.
- PC2.2.1: Isolate the key parameters associated with the dynamic of past to present changes—set up the technical system on three systemic levels.
- PC2.2.2: Formulate all the obvious assumptions regarding development of the future technical system consistent with the rest of the multi-screen scheme.

Theory and practice: Section 3: Use of laws of system evolution

Theoretical Skills to be acquired (2 hours):

- TC3.1: Understand all premises of each law.
- TC3.2: Be able to situate, discuss and develop lines of argument of past system development with relation to the laws of system evolution.
- TC3.3: Formulate system Evolution Hypotheses consistent with the definitions and premises of a law.

Practical Competence in Lab Work:

- PC3.1: Situate the system being analyzed with relation to each law.
- PC3.2: Find faults in the system being analyzed and explain their relationship to a more restricted group of laws.
- PC3.3: Formulate all the obvious assumptions

with relation to the prospects of future evolution of a technical system consistent with each of the laws.

Theory and practice: Section 4: Formulation and choice of contradictions

Theoretical Skills to be acquired (2 hours):

- TS4.1: Correctly formulate the technical and physical aspects of a contradiction.
- TS4.2: Build a group of poly contradictions.
- TS4.3: Develop a given scenario for a hierarchy of parameters.

Practical Competence in Lab Work:

- PC4.1: Differentiate between an action parameter (AP) and an evaluation parameter (EP), and between an element, a parameter and antonymous values.
- PC4.2: Ensure the completeness of all parameters when building poly contradictions.
- PC4.3: Make pertinent associations of coefficients to AP and EP respectively.

Theory and practice: Section 5: Use of a matrix for resolving technical contradictions

Theoretical Skills to be acquired (2 hours):

- TS5.1: Understand the historical and organizational background leading to the emergence of the matrix.
- TS5.2: Understand matrix functioning.
- TS5.3: Understand the meaning of a generic engineering parameter, a principle and an inventive sub-principle.

Practical Competence in Lab Work:

- PC5.1: Explain how the matrix was built and its use limitations.
- PC5.2.1: Associate specific system evaluation parameters with generic evaluation parameters.
- PC5.2.2: Isolate the most statistically appropriate inventive principles in a hierarchy to resolve a given contradiction.
- PC5.3: Interpret an inventive principle or its sub-principle and contextualize it to potentially formulate an appropriate inventive solution concept.

Theory and practice: Section 6: Interpretating inventive principles and generating solution concepts

Theory Skills to be acquired (2 hours):

- CT6.1: Understand the limits of generic expression in an inventive principle and its role in the emergence of a solution concept.

Practical Functional Variations in Lab Work:

- CP6.1: Interpret an inventive principle or its sub-principle and contextualize it to potentially formulate an appropriate inventive Solution Concept (SC).

Theory and Practice: Section 7: Characterize, select and evaluate the impact of solution concepts

Construct an overall solution on the basis of an aggregation of several solution concepts that were generated.

Theoretical Skills to be acquired (2 hours):

- TS7.1: Evaluate the inventive value of a solution concept.
- TS7.2: Aggregate solution concepts amongst themselves.

Practical Competence in Lab Work:

- PC7.1.1: Distinguish the level of inventiveness of a concept solution using the Altshuller scale.
- PC7.1.2: Correlate a solution concept to one or several laws.
- PC7.1.3: Estimate the impact of a solution concept on a group of contradictions.
- PC7.2: Aggregate solution concepts among themselves in order to extract an overall result solution for a study.

Evaluation module

A three-part evaluation of the module is done, with each part having a role in completeness of expected skills attainment in inventive design.

- Part I: Draft a 15–20 page report summarizing the study that explains the various stages of the process, the manner in which data were analyzed by the group and the choices made throughout the process that was recommended by the method.
- Part II: An academic defense, in which the group's presentation indicates consistency of the study, assimilation of TRIZ vocabulary and justification of students' choices during the lab.
- Part III: Evaluation by the professor that oversaw the groups during the labs. This part of the evaluation relates to the overall judgment of the quality and value of the study's results, and their correlation with the goals of the module.

4. Method used

The method used refers to the set of tools offered by the TRIZ theory. This method is the result of analysis of practice of teaching and learning in pedagogy made by learners and teachers in INSA of Strasbourg. Though, the underlining theory is TRIZ. Fig. 1 synthetises the steps of our pedagogical method for solving non-typical problems.

Theory sections are strung out sequentially over the semester, while the TRIZ method is not necessarily sequential. For example, Law 1, Completeness, is taught in section 1, while the other laws are not dealt with until section 3. This situation is due to the fact that no systematic manner of describing the object analyzed exists in TRIZ [16]. The only element that nears this is the law of completeness and it's breaking down into elements playing key roles in providing a MUF (Main Useful Function). Yet an analysis cannot be launched if the object of this analysis is not yet defined in a minimalist form, allowing for a possible subsequent redefinition.

The algorithm behind the software tool [17] that illustrates the methodological process used in module CE5 is provided in Fig. 1. It illustrates the sequencing between theoretical and practical phases of the module as well as digital information produced during its development.

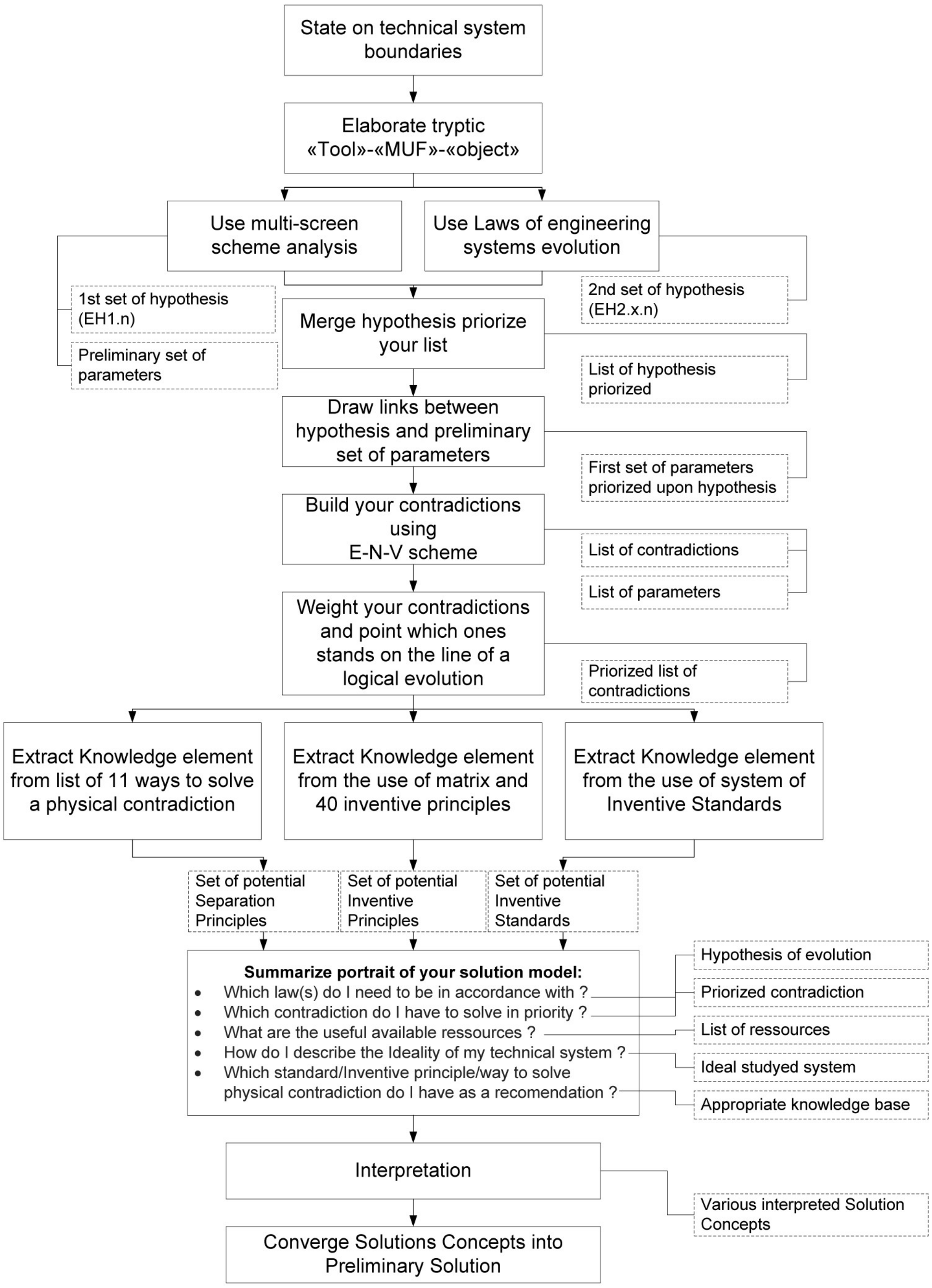

Fig. 1. Generic algorithm elaborated in the pedagogy of Module CE5.

Using the software can help in learning TRIZ. In an environment rife with knowledge and that is part of an algorithmic logic, a software program is a major advantage from two perspectives:

- Knowledge being required is necessarily explained through the underlying algorithmic logic in the software program. This reduces the vagueness that sometimes surrounds TRIZ-originated concepts.
- The current generation of students has always used computer devices in daily learning and leisure situations. The man-machine interface scheme that provides a game-like aspect tends to increase or even provoke the desire to learn in students.

For the reasons expressed in the previous section, and because of the positive aspects of the software tool, we decided to use a similar tool in lab work for the CE5 module. Software programs using TRIZ do exist. The ideas outlined in section 3 however, are not present in the five programs that we tested and analyzed. This type of tool therefore had to be defined and designed. This was true as from the first years of the experiment.

The evaluation protocol essentially dealt with Part 1 of the evaluation presented in section 3. Each time a theoretical concept is taught or implemented in a lab setting; students' work should illustrate the manner this concept is used in their project. Then, depending on the way the concept is used and how this use is explained in the report, an assessment of how well the concept has been grasped is made, as follows:

- Level 0: the concept has not been understood, it is absent in the report and the study presented by the student.
- Level 1: The concept has not been understood. It is presented in the report but is incorrect.
- Level 2: The concept has been partially understood. It is presented in the report but is incomplete.
- Level 3: The concept has been understood. It is presented in the report and used correctly.

Tables 1 to 5 summaries the themes dealt with by students over the past five years, from 2006 to 2010. They show how well the groups understood each theoretical and practical section evaluated in their reports. Each column corresponds to a theoretical and practical section and the mark shown was assigned using the grading scales presented above, from 0–3.

Table 1 describes the first year of the experiment. Students used essentially paper draft copies and the TRIZ concepts had not yet been subjected to an ontological process.

Table 2 uses conditions similar to those in 2006, with the difference that a glossary was distributed to students.

In Table 3, the first version of the software appeared. This version compiles the key stages of the lab work, Stages 1–4, but the matrix work is still done on paper. During the labs, students no longer worked on tables in groups, but rather at computer

Table 1. Subjects Analyzed in 2006 and Levels of Skills Acquisition

			2006				
Subject Title	**Law 1**	**Multiscreen Scheme**	**Laws**	**Technical Contradiction**	**Matrix**	**Solution Concept**	**Concl.**
Bike lock	1	1	1	1	1	0	0
Hairbrush	1	2	0	1	1	0	1
Folding chair	2	0	0	1	0	1	2
Windscreen wiper	2	1	0	1	1	1	1
Stirrup	2	1	1	2	1	1	2
Toaster	1	0	2	1	3	1	1
Clipboard	2	0	1	0	2	1	2
Spikes	2	0	1	0	1	0	1
Glasses	2	1	1	0	1	2	2
Glasses case	2	1	1	1	2	1	1
Pencil sharpener	2	1	1	1	1	1	2
Car deodorizer	2	1	2	0	1	1	0
Teacup	2	1	0	1	1	2	1
Tobacco measuring unit	1	1	0	1	2	1	1
Clothes peg	1	2	0	0	0	1	2
Case	2	0	1	1	1	1	1
Bicycle handlebars	2	0	1	1	3	1	3
Wire stripper	1	0	2	2	1	1	1
Rubbish bin	2	2	2	1	2	1	2
Bicycle baggage carrier	1	2	1	1	1	3	1
Table	1	1	1	2	2	1	0
Average score: 2006	**1,6**	**0,9**	**0,9**	**0,9**	**1,3**	**1,0**	**1,3**

Table 2. Subjects Analyzed in 2007 and Levels of Skills Acquisition

			2007				
Subject Title	**Law 1**	**Multiscreen Scheme**	**Laws**	**Technical Contradiction**	**Matrix**	**Solution Concept**	**Concl.**
Broom	1	0	1	1	1	1	1
Pedal operated bin	1	0	1	2	0	1	2
Bike lock	3	0	1	2	1	1	2
Trailer hitch	1	0	0	1	1	0	1
Corkscrew	1	0	0	0	1	1	1
Urinal	2	1	0	1	2	1	2
Rear brake lights	1	0	1	1	1	2	3
Glasses frame	1	0	1	3	1	1	1
Hand dryer	1	1	1	1	0	1	1
Fins	2	1	2	1	0	3	2
Contact lens case	1	2	1	3	0	1	1
Toilet brush	2	0	1	1	3	1	3
Citric squeezer	1	0	1	1	1	2	1
Doorknob	2	0	0	2	1	2	2
Recycling bin	1	0	1	1	1	1	1
Bicycle handlebars	1	1	1	3	1	2	1
Light bulb	1	2	2	1	3	1	3
Flower pot	1	0	1	3	1	2	1
Road pavement	2	0	1	1	1	1	2
Aeroponics system	1	2	2	2	1	0	2
DVD holder	1	0	2	1	3	1	1
Razor blade	1	0	0	1	2	2	1
Book bag	2	2	1	2	1	1	1
Rugby helmet	1	1	1	1	2	2	3
Soap dispenser	1	1	0	1	2	1	1
Average score: 2007	**1,32**	**0,56**	**0,92**	**1,48**	**1,24**	**1,28**	**1,6**

Table 3. Subjects Analyzed in 2008 and Levels of Skills Acquisition

			2008				
Subject Title	**Law 1**	**Multiscreen Scheme**	**Laws**	**Technical Contradiction**	**Matrix**	**Solution Concept**	**Concl.**
Watering can	2	2	2	2	2	2	2
Ice cube tray	2	2	2	2	2	2	3
Thermostatic bottle	2	1	2	2	2	2	2
Snake	0	2	2	2	2	2	2
Can opener	2	0	2	3	2	2	2
Video projector booster	2	2	2	2	1	2	2
Siphon	2	3	2	2	3	2	2
Chains	2	1	3	2	2	3	2
Nail trimmers	2	1	2	0	2	2	2
Computer power supply	2	2	2	2	2	2	2
Vice	2	0	2	2	2	2	3
Lamp	2	1	2	2	2	1	3
Rubbish bin	2	0	1	2	2	2	2
Socket	2	2	2	2	2	2	2
Alarm clock	2	2	2	3	2	2	2
Headrest	2	2	2	2	2	1	2
Watchband	2	1	2	2	2	2	2
Ashtray	2	2	2	2	2	2	2
Adjustable spanner	2	1	3	2	3	2	2
Shopping cart	2	2	2	2	2	2	3
Pasta holder	2	3	2	2	2	2	2
Remote control	2	2	2	2	2	2	2
Average score: 2008	**1,9**	**1,5**	**2,0**	**2,0**	**2,0**	**2,0**	**2,2**

work stations with an area allotted for making written notes and to discuss opposite the screen. The software, a Java applet, was accessed via a server and students saved their work on an XML file that they could subsequently use again.

Access to the server software was also available outside of lab hours.

In Table 4, the software is provided together with definitions of terms and the examples of previous years are made available to students. Thus, where a

Table 4. Subjects Analyzed in 2009 and Levels of Skills Acquisition

2009							
Subject Title	**Law 1**	**Multiscreen Scheme**	**Laws**	**Technical Contradiction**	**Matrix**	**Solution Concept**	**Concl.**
Soap dish	3	2	2	2	2	2	2
Ironing board	2	2	2	2	2	2	2
Cutting board	2	2	2	3	1	2	2
Crutches	3	2	3	3	2	3	2
Motorbike frame	2	2	2	1	2	2	1
Mixing valve	2	1	2	2	3	2	2
Bass pedals	2	3	2	2	2	2	2
Power strip	1	3	3	3	2	2	2
Fan	2	3	3	3	2	3	2
Kettle	3	2	3	2	2	1	2
Tape dispenser	3	2	3	2	2	3	2
Rectangular milk carton spout	3	2	2	2	2	3	2
Paint roller	2	2	1	2	2	2	2
Hammock	1	2	2	2	2	2	1
Broom	3	2	2	1	2	2	2
Brush	2	2	2	2	3	2	2
Scissors	2	2	2	2	2	2	2
Coat rack	2	1	2	2	1	2	2
Mattress	2	2	2	2	2	2	2
Average score: 2009	**2.2**	**2.1**	**2.2**	**2.1**	**2.0**	**2.2**	**1.9**

Table 5. Subjects Analyzed in 2010 and Levels of Skills Acquisition

2010							
Subject Title	**Law 1**	**Multiscreen Scheme**	**Laws**	**Technical Contradiction**	**Matrix**	**Solution Concept**	**Concl.**
Perfume dispenser	3	3	2	3	2	2	2
Key chain	3	2	1	2	3	2	2
Carafe	2	3	2	2	3	2	1
Beverage can top	3	2	2	2	2	3	3
Ski gloves	2	2	2	3	3	3	2
Instant hot water heater	3	3	3	2	3	2	3
Screwdriver	2	3	3	3	2	3	3
Cheese grater	3	3	3	3	3	3	2
Board eraser	2	3	2	3	3	2	3
Toilet door locking system	3	2	3	3	3	2	2
Tool box	3	2	3	3	3	3	3
Egg breaker	3	2	2	3	2	2	2
Mixer	2	3	3	3	3	3	2
Wetsuit	3	2	3	3	2	3	3
Coffee filter	3	3	2	2	3	2	1
Measuring cup	2	3	3	2	2	3	2
Lipstick	3	3	3	3	3	2	3
Average score: 2010	**2.6**	**2.6**	**2.5**	**2.6**	**2.6**	**2.5**	**2.3**

concept is still murky after the class, students can either ask questions through a specially devised forum or they can consult any report from previous years to find a response.

In Table 5, the software reached maturity and now includes rules for completing tasks. Whenever a key step along the overall exercise is entered, an algorithm automatically displays any of the three possible levels of completing it: Black (subject not dealt with); Orange (Subject dealt with, but incompletely); Green (Subject fully processed). A methodological supplement is also provided that deals with the points that were deemed "poorly understood" in previous years. The supplement comes in a standard question form for each system evolution law. The form encourages students to ask themselves certain questions relative to each law and it formalizes the way to respond.

The documents for 2011 are not yet available, as they are still in development. Student comments are registered systematically. In upcoming experiments, the evaluation stages for arriving at solution concepts for apparent contradictions will be dealt with in class and formally introduced during lab sessions.

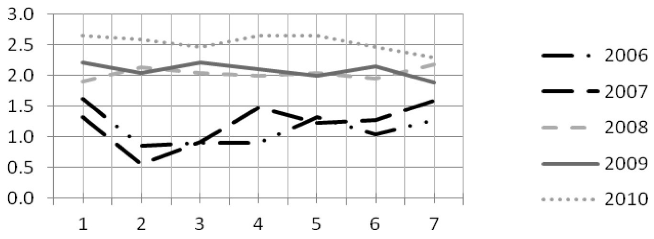

Fig. 2. Curve Showing Average Scores by Year (2006–2010).

5. Analysis of results

In this section, we analyze the 2006 to 2010 results presented in the previous section. Fig. 2 summarizes these five years, with trends in student results for the seven theoretical and practical sections of learning the TRIZ concept.

It is clear that the 2006 and 2007 curves are grouped well below those for 2008 through 2010. The formalism provided through the software undeniably contributes to improving scores. However, these earlier curves also show that performance in Sections 2 and 3 was not as good as in the other sections. This led us to analyze the reasons that system evolution laws were used only vaguely in the studies, even though they occupy a full course module of two hours of lecture and two hours of lab work. To address this, work was initially done to render the use of laws systematic. The early results of this effort were outlined in an article. It was observed that the subject of law usage remained poorly understood during the 2008–2010 period, though to a lesser extent.

Finally, we also noted that scores in Section 7 fell off a little. As this section did not include software use, we intend to improve the way solution concepts are classified and their impact evaluated in upcoming years by adding a new function that is aligned with the theoretical elements of the course.

Comparative analysis of two student projects from sections 2 and 3 of module CE5: Hanger–A 2006 study, and Watering Can—A 2008 study

Note: Student's results will be provided in Italic characters in the next sections.

Section 2: Multi-screen scheme for a hanger. Study by engineering students Frédéric Marchat, Sébastien Lommele and Vincent Schultz.

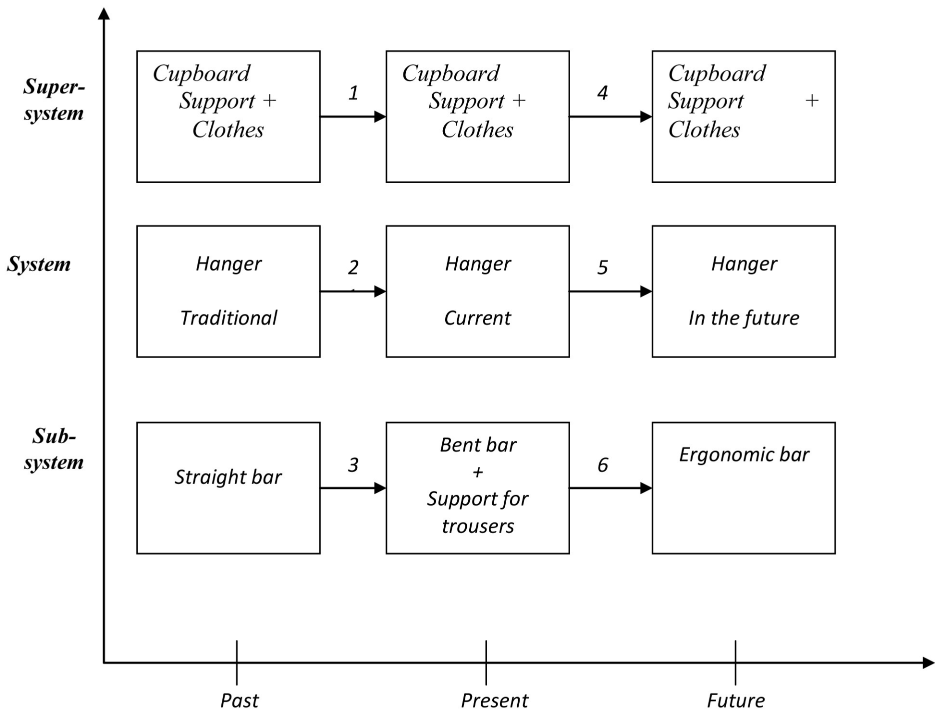

Fig. 3. Multi-screen Scheme for a Hanger (2006).

Details of transitions:

1. No special modifications / A bar on which to hang the hangers.
2. Add a function: Make it possible to place a pair of pants and/or a sweater on the same hanger. The hook can revolve, less expensive plastic materials, easier to fabricate than wood, but also more fragile.
3. More ergonomic shape, offering both an advantage and a drawback. This lessens hanger deformation when the sweater is placed on the hanger but increases it when pulled through the neck, making it necessary to bring the hanger up from below.
4. The hanger should be able to carry all clothing types, which could imply modifications to the bar in the closet.
5. Add a function: Eliminate the hook, which implies changing the bar, and create universal hangers for all sizes.
6. Improves ergonomics because the hanger is adjustable.

Section 2: Multi-screen scheme for a watering can. Study by engineering students Matthieu Binder, Flavien Verjat and Mathieu Riffaud.

Future screens are discussed and the following content observed (Evolution Hypothesis and their associated parameter).

There are several differences in results with use of the multi-screen tool in Section 2 (Figs 3–5). The Hanger team has many fewer system evolution hypotheses in its object. The Present—Future transfer is intuitive, making the capacity to predict less reliable. The Watering Can team based its system evolution potential on all parameters that influenced the Past—Present evolution. Because of this, assuming their analysis of historical facts is correct, it would appear that their system evolution predictions will be more constant than those of the hanger team. This evolution is observed statistically on the 0–3 evaluation scale that we set up as ranging from 1.9–2.1. It confirms clear improvement for at least three years of continuity in scores for the 59 projects carried out between 2008 and 2010.

Example: Section 3: Use of Evolution Laws in Projects [18].

The hanger project was evaluated at 1 in Use of laws for the following reasons: Only Law 1 is used, and there is no hypothesis linking this section of the analysis to the rest of the study.

Step 4. Logic of evolution

We have two types of energy in our system:

- Gravitational
- Mechanical

The Watering Can study underwent a much more exhaustive analysis, receiving a grade of 3, in which all the laws were applied and were linked up with the parameters at the origin of the contradictions.

No comparison may be drawn regarding use in Section 2 in an analysis of the approaches to the hanger and the watering can. The hanger team did

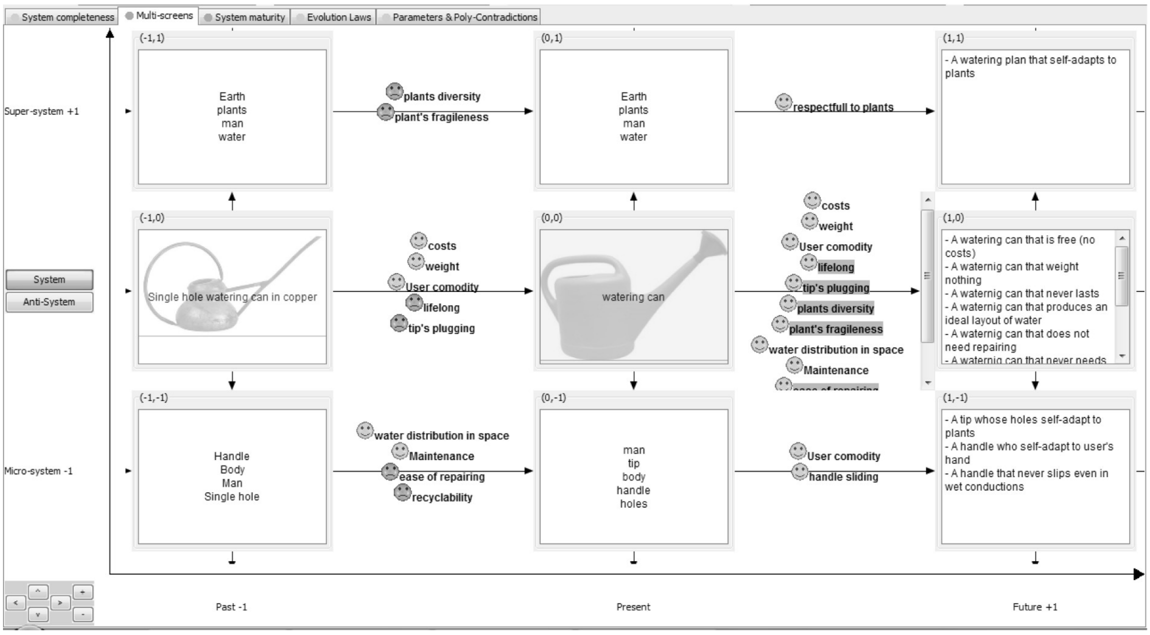

Fig. 4. Multi-screen Analysis for a Watering Can (2008).

Box (1,1):
A watering plan that self-adapts to plants

Box (1,0):
A watering can that is free (no costs)
- costs
A waternig can that weight nothing
- weight
A waternig can that never lasts
- lifelong
- recyclability
- ease of repairing
A waternig can that produces an ideal layout of water
- Water distribution
- ability to regulate flow rate
A waternig can that does not need repairing
- Maintenance
- tip's plugging
- costs
A waternig can that never needs maintenance
- Maintenance
- ease of repairing
- lifelong
- tip's plugging
- costs
A waternig can that never gets plugged
- ease of repairing
- lifelong
- Maintenance
- tip's plugging
- Water distribution
- ability to regulate flow rate
- water distribution in space
A waternig can that self-adapt to its user
- Maintenance
- tip's plugging
- Water distribution
- ability to regulate flow rate
- water distribution in space
- weight
- quantity of transported water
- Ease of water transportation
- User commodity

Box (1,-1):
A tip whose holes self-adapt to plants
- ability to regulate flow rate
- ease of water direction control
- System's complexity
A handle who self-adapt to user's hand
A handle that never slips even in wet conductions
- handle sliding
- User commodity

Fig. 5. List of EH-EP links for a Watering Can (2008).

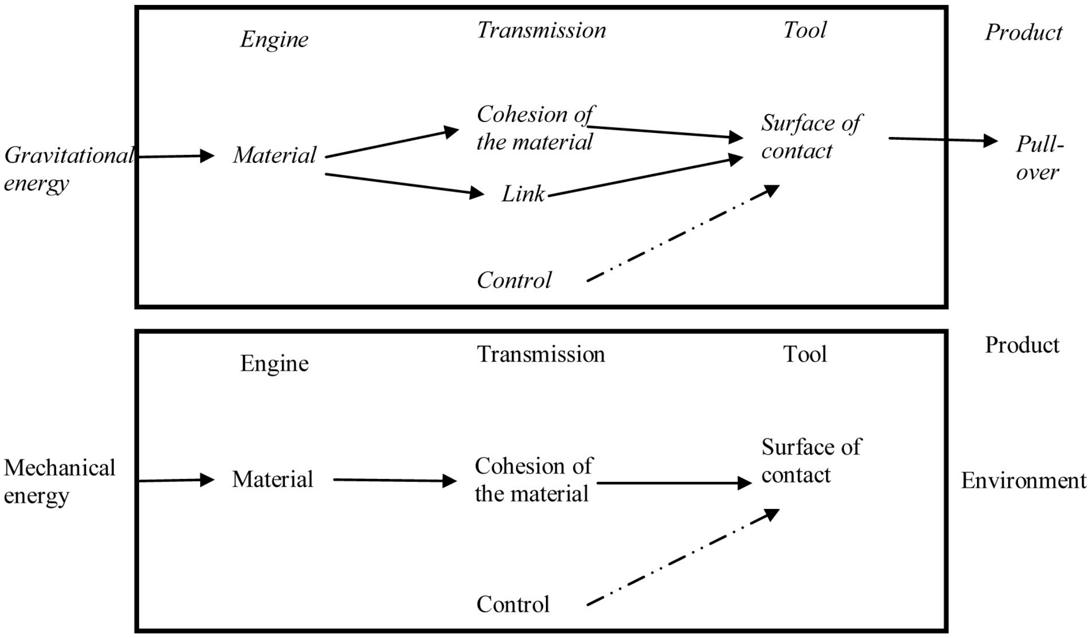

Fig. 6. Analysis of Laws for the Hanger (2006).

not use the theoretical course module in its lab work while the watering can team incorporated it mostly. Although it could be argued whether a more formal methodological approach on paper might have improved the hanger team's score, we must acknowledge the undeniable edge provided by use of the IT tool. Not only does it fill the methodological gap in traditional TRIZ studies by formalizing the relationship between system evolution laws and the parameters at the root of contradictions [19], but it also simplifies use of the process by systematically saving knowledge acquired in previous stages, which would not have been an easy task without the software functions. In the pre-software teaching

Fig. 7. Screen capture of the analysis of Laws for the Watering Can (2008)<

1. System completeness
A watering can that self-adapts its water flow rate (Law n°1)
- *ease of water direction control*
- *ability to regulate flow rate*
- *System's complexity*

A tip that self adapts to the type of plants (Law n°1)
- *water distribution in space*
- *ability to regulate flow rate*
- *ease of water direction control*
- *Water distribution*

A handle that adapts to the user (Law n°1)
- *handle sliding*
- *water distribution in space*
- *User commodity*

2. Energy conductibility
A watering can that reduces user efforts when carrying it (Law n°2)
- *Ease of water transportation*
- *handle sliding*
- *weight*
- *quantity of transported water*
- *User commodity*

A watering can whose tip does not produce flow rate losses (Law n°2)
- *ability to regulate flow rate*

3. Harmonization
A handle that self-adapts its tip's position (Law n°3)
- *ease of water direction control*
- *ability to regulate flow rate*
- *System's complexity*

A handle diposed in such a way that we can obtain a good body balance (Law n°3)
- *Ease of water transportation*
- *quantity of transported water*
- *User commodity*
- *System's complexity*

4. Ideality
A watering can of a minimum volume (Law n°4)
- *quantity of transported water*
- *Ease of water transportation*
- *User commodity*

A watering can with a minimum weight (Law n°4)
- *quantity of transported water*
- *weight*
- *User commodity*

A watering can that is self filling (Law n°4)
- *Ease of water transportation*
- *quantity of transported water*

5. Irregular evolution of the parts
No formulated hypothesis

6. SuperSystem transition
A self-watering earth (Law n°6)
- *quantity of transported water*
- *Ease of water transportation*

An earth that does not need water (Law n°6)
- *Ease of water transportation*
- *quantity of transported water*

7. Microlevel transition
A tip constituted of several sub-tips in order to vary the opening and water flow rate (self-adaptative flow rate) (Law n°7)
- *ability to regulate flow rate*
- *ease of water direction control*
- *Water distribution*
- *water distribution in space*
- *System's complexity*

8. Dynamisation
A watering can flexible on any dimensions (Law n°8)
- *Ease of water transportation*
- *User commodity*

9. Interaction Substances Fields
A watering can that distribute an additional component (like fertilizers) (Law n°9)
- *Maintenance*
- *System's complexity*

Fig. 8. EP-EH link for the Watering Can (2008)

phase, prior to 2008, the laws were simply admitted; in the post-software period, after 2008, they become integral parts of the study.

6. Discussion

The results of the preceding case study clearly show an increase in pedagogic effectiveness in teaching inventive design. The gain is directly attributable to the introduction of software to the process. Other factors may come into play to explain gains in pedagogic effectiveness. The "Instructor" effect, highlighted by Marie Duru-Bellat in [20] could explain why diversity at the level of instructors is accompanied by a variation in scores indicating acquisition of knowledge of inventive design. Nonetheless, there were no new instructors during the reference period; the course was given by a single person. The instructor effect shows that success at teaching a course may also depend on the individual characteristics of a single person, such as training, past experiences, personality and ability to listen. Having conducted an evaluation on pedagogic effectiveness over several years, we can now affirm that this instructor effect is under control. While differences emerge from one year to the next, they are not due to a change in instructor nor in that person's characteristics themselves, barring a major change in the personal characteristics of an instructor. The instructor concerned has not changed significantly. Changes in pedagogy could have been observed if the instructor had trained in the method, or if other instructors taught part of the course.

Another possible source of variation could be the cognitive learning of students [21]. This variation may be observed amongst individuals of a like class over a finite period of time. It may also be observed from one year to another if students come from widely different educational backgrounds. Thus, any diploma earned prior to entering the fifth year should be taken into account. It must be acknowledged that most of the students in our school have different initial higher education backgrounds. The greater majority of students, 80% in fact, took up generalist preparatory courses after secondary school, while the remainder engaged in shorter, technical oriented courses in technological institutes. Over our five year observation period, this balance has not altered. In contrast, academic content of the preparatory courses in our school has changed. They have become more specialized in civil, mechanical or electrical engineering in the second year. While this specialization does not appear to have a direct impact on the educational levels when approaching inventive design in the fifth year, it must be acknowledged that some newly introduced modules, such as project methodology, do have an impact on the success rate in inventive design. Nevertheless, the two years between the ends of the first and second cycles of the engineering course tend to strongly attenuate this type of impact. In addition, these two years are common to all students. We therefore turn to the introduction of the software to find out why pedagogic effectiveness has improved over the past five years.

An analysis of the results of the previous section shows that the instructor came to reconsider the teaching method used, as evinced by the design of a software program. This opportunity to re-design the course facilitated interaction between students and instructor by making knowledge targeted by the course more rapidly and autonomously accessible. The software appeared as the solution for didactically improving the course by contributing to the accuracy, structure and clarity of course content. From the students' perspective, the use of the software not only provided a game-like and motivational aspect, but it contributed to making the pedagogic relationship more active. Students have an additional element available to them to use in acquiring knowledge. This element is a genuine symbol for them in that it crystallizes the design practices that the instructor no longer needs to specify. Students therefore gained in terms of interaction with the instructor, without necessarily having to initially make direct contact with the instructor. As such, the software constitutes a "haven" during a crucial stage of the course. The beginning of a course is a difficult stage in any pedagogic relationship. Instructors establish a framework for their course, while students seek meaningful landmarks for their learning experiences. The use of a software program at this time reassures students by avoiding the direct interface with instructors. The software acts as an intermediary for relationships with the instructor, and both furnishes a framework, a landmark and an objective occasion for interaction between students and the instructor.

7. Conclusion

This article proposed a framework for evaluating a pedagogic experiment in inventive design. The technological dimensions, with the introduction of a software program, were assimilated in interaction with the pedagogic dimensions. A link was clearly established between the introductions of a software program, the development of active pedagogies and improved teaching effectiveness in the inventive design skills acquisition process. However, certain limitations now appear more clearly. The advantage of the instructor's uniqueness is also a drawback.

We have no indication that, based on the current results of this experiment, the method it is transferrable to other teachers. The same is true for the uniqueness of the establishment. Learning institutions, especially in an international environment, have their own characteristics depending on the culture of the country. Widespread experimentation of the concept with other institutions could be attempted in future research in the area.

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