

Systematic Creativity Methods in Engineering Education: A Learning Styles Perspective*

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The traditional approach to creativity (using methods such as brainstorming, C-sketch, morphological charts, scamper, etc.) calls upon the designer to look inward for inspiration. TRIZ, on other hand, invites the designer to use a ready pool of knowledge for inspiration. TRIZ does not discount the use of the traditional approaches. On the contrary, TRIZ ensures that design teams use these traditional methods in a systematically directed manner by carrying out intelligent idea generation in areas where other people have solved a similar general design problem. The main focus of this paper is to look at systematic creativity methods, such as TRIZ, from a learning styles perspective. Three learning styles dominant in the engineering education literature are explored: MBTI, Kolb and Felder-Silverman. For each it was found that the tasks required of each of the TRIZ steps matches a broader range of engineering student learning styles, than the sole use of brainstorming.

Keywords: creative problem solving; TRIZ; learning styles.

INTRODUCTION

ALTHOUGH the literature is filled with varied definitions of creativity, they all seem to capture the notion that creativity is the ability to find new ways to use existing knowledge to solve problems, and to produce novel works that are valued by society [1, 2]. Within the context of engineering design, the level of creativity is predicated on, amongst others:

1. desire and fulfillment;
2. knowledge of objects and principles possessed or available (knowing how to obtain the needed knowledge and how to use it) that includes implicit knowledge gained in experiences, heuristics, and instinct ('gut' feeling);
3. openness, i.e. a willingness to accept criticisms and ideas from others;
4. knowledge of process, especially design and problem solving processes [3–5].

Whereas (1) and (3) are personality traits, (2) and (4) must be learnt, and are typically inadequately developed in engineering students. Popular idea generation methods, such as brainstorming (and its variants) that rely heavily on (2), when used as the sole vehicle to creativity, therefore, often fall short.

Brainstorming calls upon the designer to look inward for inspiration on creative solutions to problems, by drawing upon past experiences and knowledge. This can be a daunting task that may or may not be fruitful. This is especially true for undergraduate students whose past engineering

knowledge and experiences are still quite limited. As noted by Wood *et al.* [6], 'Some students do not adapt well to having extremely open-ended problems as the first assignments they encounter. This may not necessarily be because they have trouble with open-ended problems (intellectual maturity), but because they lack the engineering elements to use to fill the blank sheet design.' This point is driven home further by Simon [7] who postulated that to become creative, one needs to accumulate about 50,000 knowledge bits, be able to see the relations between them, and apply knowledge from one area to another.

Several models have been put forth for the creative process [5, 8]. A widely accepted model is the Helmholtz-Poincaré-Getzels (HPG) model of creativity, initiated in the 19th Century by German physicist and physiologist Herman Helmholtz, and later modified by French mathematician Henri Poincaré, and further developed in the 1960s by American psychologist Jacob Getzels [9]. The model consists of five stages:

- a) *First insight* – understanding and formulation of problem. Speculation on possible solutions.
- b) *Saturation* – information gathering phase. Immersion into the problem details including what is available that could be used to solve the problem. Generation of preliminary solution concepts.
- c) *Incubation* – the mind gets frustrated or stuck and the problem is put aside for a while.
- d) *Illumination* – the person gets an insight, flash of recognition of the solution during mental down times, for example when showering, eating, or jogging. They stumble upon the

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answer unexpectedly and, therefore, this stage involves an element of luck.

- e) *Validation*—analytical process to verify solution and put in form others can use.

The later stages of (b) saturation and stages (c) incubation and (d) illumination present the greatest challenge to the novice designer. Successful incubation (unconscious processing of information) and illumination assumes that the designer has unconnected bits of qualitative knowledge stored in the brain that can be internally or externally triggered to collectively synthesize a novel idea or concept. For undergraduate students (novice designers) this knowledge is still limited.

The focus of this paper, therefore, is to take a critical look in the context of learning styles, at how systematic creativity methods such as the theory of inventive problem solving (TRIZ) can reduce the challenges presented by stages (b), (c) and (d), as compared to the sole use of popular creativity methods such as brainstorming (and its variants). The following section briefly discusses the HPG creativity model in the context of the engineering design process. This is followed by an overview of three common learning style models found in the engineering education literature. After an introductory description of TRIZ, a comparison is made between ideation with the sole use of brainstorming, and with the use of TRIZ from a learning styles perspective. The paper concludes with a discussion on the implications to engineering design education.

CREATIVITY AND THE ENGINEERING DESIGN PROCESS

Over the past twenty years, engineering design has been viewed to involve more ‘science’ and less ‘art’. Although engineering design requires creativity and inventiveness (‘the art’), engineering design is a process that can be taught, learned and successfully implemented to solve engineering problems (‘the science’) [10, 11]. The engineering design process can be divided into five broad

sequential steps: needs assessment/problem definition, conceptualization, preliminary design, detailed design and production. The main tasks done during each of these steps are summarized in Table 1. It must be emphasized that engineering design is an iterative process often requiring cycling between the steps based on what is learnt later on.

In the classroom, most student design teams only go through the first three stages of the design process: determination of need, conceptualization and preliminary design. During these three stages, the following observations can be made [11, 12]:

- In the *needs assessment/problem definition* and *preliminary design* stages, the tasks are more certain and structured following a step-by-step process, often referred to as ‘mechanical’ tasks in the literature [13, 14]. However, surprises or unexpected outcomes do occur requiring creativity from the team members to overcome them. Design tasks in these phases are often referred to as ‘incremental’ in the literature [15] as they tend to focus on incremental innovation or small improvements to existing products or existing concepts.
- In the *conceptualization* stage, the tasks are less certain, less structured, more dynamic, and requires more creativity from teams. This design phase is often referred to as ‘radical’ (also referred to as ‘innovating’) in the literature [15]. Design tasks in this phase suggest operating in a dynamic environment, emphasizing initiative and risk taking [12].

The HPG creativity model can be viewed in the context of engineering design by superimposing it with the first three steps of the design process as shown in Fig. 1. *Saturation* (HPG model) straddles the latter part of the *needs assessment/problem definition* and *conceptualization* steps of the design process. It is with this latter part of the saturation that ideation methods such as brainstorming and TRIZ are employed. Note that there is significant iteration between the saturation, incubation and illumination steps in the HPG

Table 1. Summary of activities performed during design stages [11]

Design Stage	Typical activities/tasks
I. Needs assessment/ Problem Definition	Statement of what design should accomplish; listing of constraints; decomposition to smaller manageable problems; compilation and weighting of customer needs; definition of criteria to be used to evaluate final design.
II. Conceptualization	Involves two steps: (1) <i>External search</i> : determine what has been done in the past. Achieved by looking at competitors’ products, patents, published literature, discussions with experts, etc. (2) <i>Internal Search</i> : generation of several concepts by the design team to best solve the sub-problems and the overall problem.
III. Preliminary design	Further development of concepts shown to be feasible. System and component design requirements are established. If applicable a working prototype is built and tested.
IV. Detailed Design	Final manufacturing and assembly drawings are generated. Systems specifications are developed (operating parameters, maintenance and testability provisions, material requirements, design life, packing requirements, etc.)
V. Production	Determination of production sequence of operations, selection of jigs, fixtures and tools; production of product.

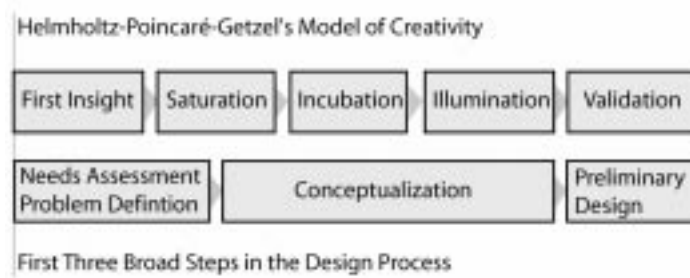


Fig. 1. Overlay of the Helmholtz-Poincaré-Getzel's model of creativity and the first three steps in the engineering design process.

model. The end result of which is the generation of several promising concepts that are validated (HPG model) during the preliminary design step of the design process.

LEARNING STYLES

Learning styles can be defined as an individual's different strengths and preferences for the ways in which they absorb and process information [16]. Three learning style models have been widely accepted in the engineering education literature: The *Myers-Briggs Type Indicator* – MBTI [17], the *Kolb model* [18, 19] and the *Felder-Silverman model* [20, 21]. A brief description of each follows in chronological development order.

MBTI

Based on Jungian typology of personality types, the MBTI tries to measure in what ways people process information and make decisions, i.e. their cognitive style. Four dimensions in this typology form continuous scales [17, 22]:

1. *Introvert* (try things out, focus on ideas) to *extrovert* (think things through, focus on people);
2. *Intuitive* (imaginative and concept oriented) to *sensing* (practical, detailed oriented, focus on facts and procedures).
3. *Feeling* (make decisions based on emotion) to *thinking* (make decisions based on logic and rules),
4. *Perceiving* (adapt easily to changing conditions, wait for complete data to reach conclusions) to *judging* (follow agendas, can reach conclusions with incomplete data).

The first two dimensions relate more to ways of behaving and approaching problems, while the latter two relate more to emotional and personal responses. Combined they can describe sixteen different learning styles.

Kolb's model

The Kolb model assesses learning styles along two continuous dimensions [18]:

- *active experimentation to reflective observation* representing how information is taken in;

- *concrete experience to abstract conceptualization* representing how information is processed.

With reference to the Kolb Model of learning (Fig. 2), Kolb identified four different learning types represented by each of the four quadrants in the figure:

- Type 1—*diverger* (concrete-active) responds well when current information is placed in context of the larger picture.
- Type 2—*assimilator* (abstract, reflective) responds well to information presented in a logical fashion. Prefer time for reflection.
- Type 3—*converger* (abstract, active) responds well to active engagement on well-defined tasks and to learn by trial and error.
- Type 4—*accommodator* (concrete, active) responds well applying known information to solve new problems.

Each type is characterized by a favorite question as shown in Fig. 2 [18, 19, 22]. McCarthy [19] combined the Kolb and other learning theories to develop the 4MAT learning system that postulates that learning occurs best by passing through each of the four quadrants of the learning cycle as shown in Fig. 2, starting in the *why* quadrant. Cyclical movement through each quadrant ensures that time is spent at each of the learning styles. From a teaching perspective, this can be viewed as motivating each new topic (Type 1), presenting the

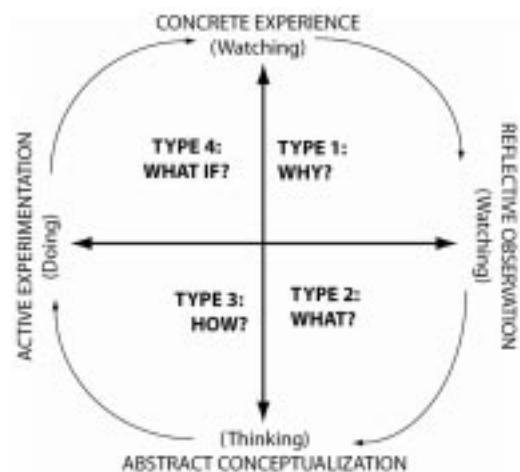


Fig. 2. Kolb's model.

basic information and methods related to the topic (Type 2), allowing the methods to be practiced (Type 3), and encouraging the application of the methods to new areas (Type 4) [22]. Studies have produced anecdotal evidence that teaching through the cycle helps students become independent learners and thinkers and that they learn new concepts more efficiently [3, 22, 23].

Felder-Silverman model

Developed in 1988, the model is designed to capture the significant learning style differences amongst engineering students. The model determines student preferences along four continuous dimensions [16]:

- Perception of information: *sensing* (practical, oriented towards facts and procedures) to *intuitive* (abstract, innovative, theory oriented). Identical to the intuitive-sensing scale in the MBTI model.
- Perception of sensory information: *visual* (preference for visual representations—diagrams, figures, flowcharts) to *verbal* (preference for verbal explanations);
- Processing information: *active* (trying things out, working in teams) to *reflective* (thinking things through, working alone). Identical to the active-reflective scale in the Kolb Model.
- Progress towards understanding: *sequential* (linear thinking process, small incremental steps) to *global* (holistic thinking, large steps).

The four dimensions yield a total of 16 possible learning preferences.

THEORY OF INVENTIVE PROBLEM SOLVING (TRIZ)

TRIZ was first developed in Russia by Genrich Altshuller and is now used across the world. It was originally based on analyses in the early sixties and seventies of thousands of Russian patents. These original analyses articulated numerous solution patterns found across patents that can be successfully applied to solve new problems. These patterns have since been synthesized into numerous tools including (1) physical effects, (2) laws of evolution, (3) standard solutions, (4) technical contradictions and the contradiction matrix, and (5) physical contradictions and the separation principles.

TRIZ has been recognized as a systematic concept generation process that can develop novel solutions to problems by using the condensed knowledge of thousands of past inventors. It provides steps that allow design teams to avoid the ‘psychological inertia’ that tends to draw them to common, comfortable solutions when better, non-traditional ones may exist. With reference to Fig. 3, a design team using TRIZ converts their specific design problem to a general TRIZ design problem. The latter is based on the analysis

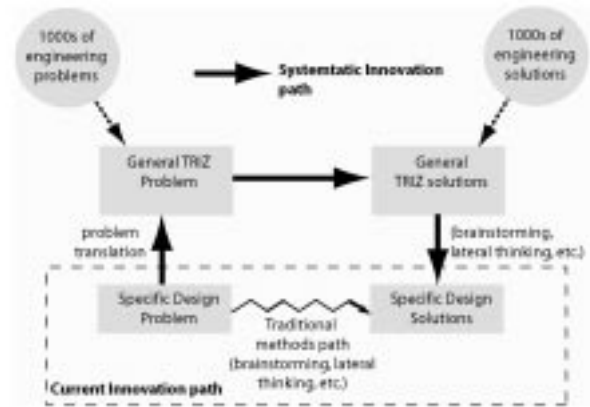


Fig. 3. Generation of design solutions using TRIZ.

and classification of a very large number of problems in diverse engineering fields. The general TRIZ design problem points to corresponding general TRIZ design solutions from which the design team can derive solutions for their specific design problem. The power of TRIZ, therefore, is its inherent ability to bring solutions from diverse and seemingly unrelated fields to bear on a particular design problem, yielding breakthrough solutions.

Recall that (1) creativity is the ability to use *existing knowledge* to solve problems and produce novel works valued by society, and (2) novice designers normally lack sufficient domain knowledge resulting in low levels of creativity. Drawing from solution patterns and general design principles synthesized from design knowledge contained in thousands of patents, TRIZ supplements the limited knowledge the designer may have by suggesting possible solution directions applicable to the current design problem, thereby increasing the level of creativity.

Traditional creativity using methods such as brainstorming, analogical thinking, mind mapping, attribute listing, and idea checklists [24–26] calls upon the designer to look inward for inspiration. TRIZ, on the other hand, invites the designer to use a ready pool of knowledge for inspiration. It does not discount the use of the traditional approaches. On the contrary, TRIZ ensures that design teams use these traditional methods in a systematically directed manner by carrying out intelligent idea generation in areas where other people have solved a similar general design problem. Detailed descriptions of the TRIZ methods can be found in [27–30].

TRIZ AND BRAINSTORMING FROM A LEARNING STYLES PERSPECTIVE: IMPLICATIONS FOR ENGINEERING EDUCATION

In order to illustrate the potential educational benefits of introducing systematic creativity methods such as TRIZ in conjunction with

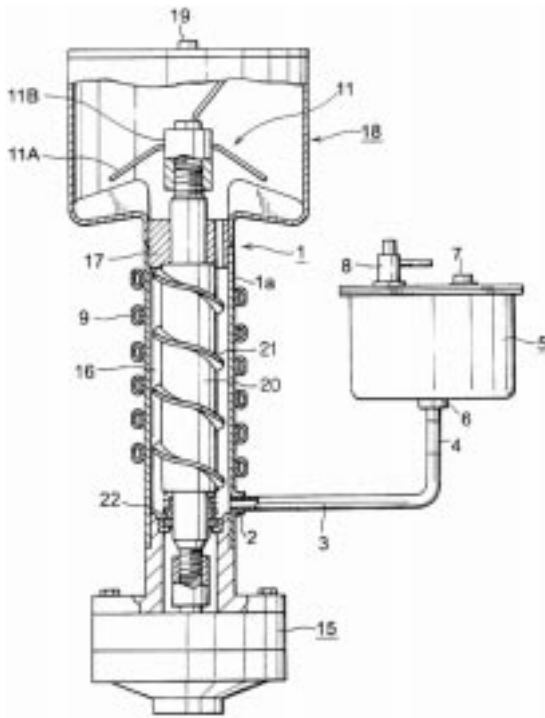


Fig. 4. Schematic of ice dispenser example [31].

traditional methods to undergraduate students, a discussion of TRIZ and brainstorming in the context of the three learning style models follows.

TRIZ in the context of MBTI

A design example will be used to illustrate the dominant personality trait along each of the four MBTI dimensions during the four states of ideation with TRIZ as illustrated in Fig. 3.

Example: Ice Dispenser (developed from [31]). With reference to Fig. 4, an ice maker/dispenser consists of an ice maker 1 with an ice-making cylinder 1a located at the center and an ice storage compartment 18 on top of the ice maker. In the ice

storage compartment, an agitator 11 is actuated periodically to prevent the ice from melting and sticking together to form large chunks that could prevent the smooth dispensing of the ice and that could result in the deterioration of the ice quality. The agitator rotates under three independent conditions: (1) each time the ice is dispensed, (2) after a set period of time, and (3) each time the ice-making process is stopped (storage compartment is full). Situations arose where the agitator ran two or three times consecutively. The agitation could last twice as long, for example, if ice is dispensed right after the ice-making process stopped. On the other hand, it could last three times as long if, for example, the pre-timed agitation is initiated right after ice is dispensed, which occurs right after the ice making process is stopped. The extended run of the agitator results in some melting of ice due to the frictional heat generated between the ice cubes and the agitator fin 11A, causing some fusion of the ice that the agitation was supposed to prevent.

Step 1: Problem clarification seeks to find the true nature and cause of the problem. It ensures that ideation efforts are directed at solving the right problem. It involves performing needs assessment, external search for what has been done to solve the problem, in this or similar contexts, determination of what the competition has done, and may include product dissection and reverse engineering, etc. Visual aids such as black-box modeling, EMS models [32] may be used to clarify the true nature of the design problem. An EMS model of the current example problem is shown in Fig. 5. In addition to showing the *harmful effect* (mechanical energy) between the agitator and the ice, the other relevant resources in the system are clearly indicated.

In the context of the MBTI model, this step could be said to be most comfortable with individuals whose dominant personalities are (Fig. 6):

- extrovert
- sensing

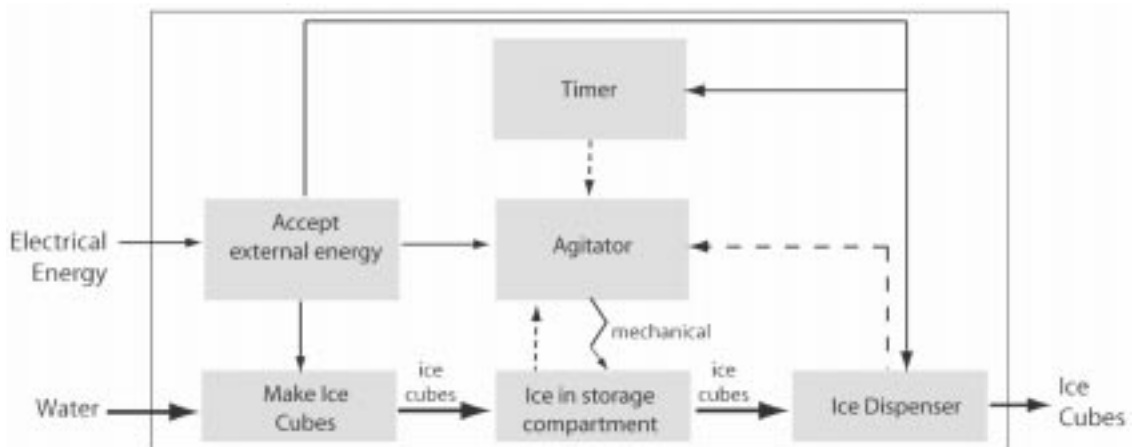


Fig. 5. Energy-Material-Signal model of ice maker showing *harmful effect* (mechanical energy) of agitator on the ice stored in the ice storage compartment.

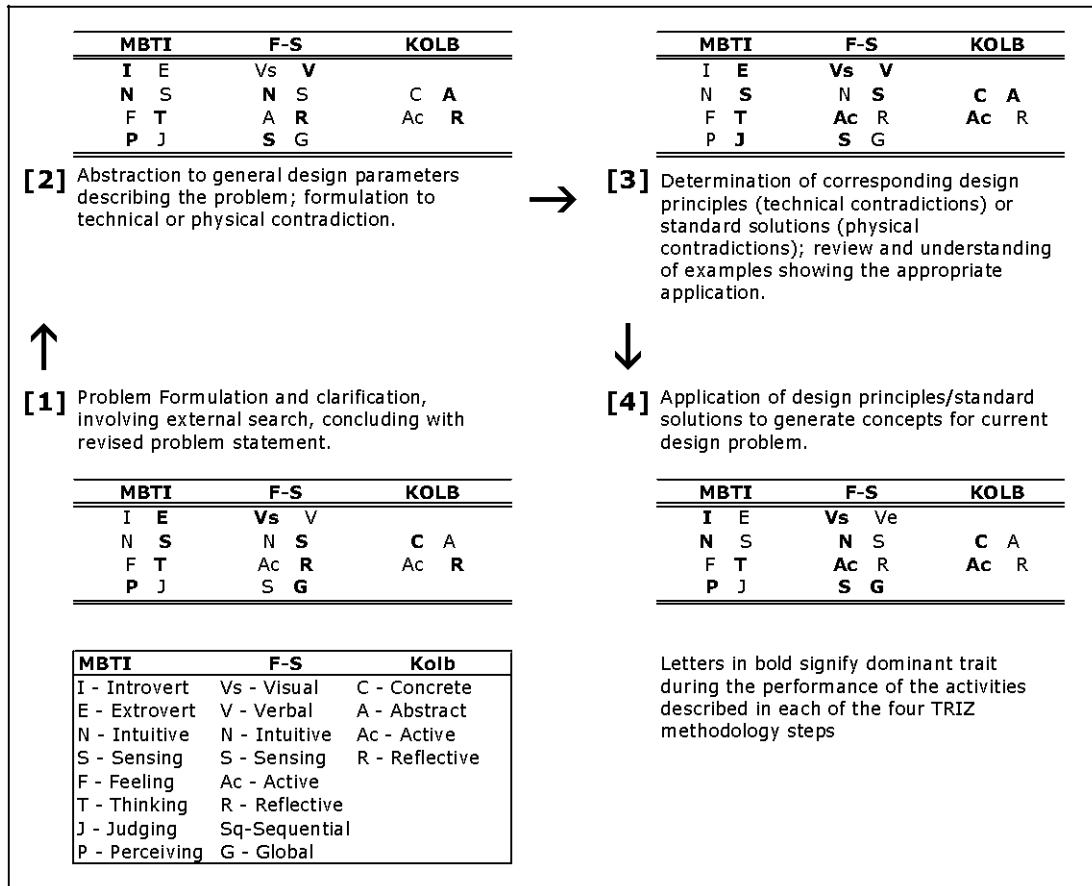


Fig. 6. Dominant learning style dimensions in each of the four general TRIZ creativity steps as defined by MBTI, Felder-Silverman and Kolb models.

- thinking
- perceiving

Step 2: Abstraction to general TRIZ problem. The details will change depending on the TRIZ tool employed, but the general approach is the same. For this example, technical contradictions and the contradiction matrix will be used. Technical

contradictions refer to the standard engineering trade-offs, i.e., changing one parameter to make an aspect of the system better makes another aspect of the system worse. For example, increasing the stiffness of an airplane’s wings to reduce vibration during flight (good) increases the weight of the plane (bad).

During this step the designer first determines

Table 2. General parameters used to describe engineering systems

1 Weight of moving object	21 Power
2 Weight of stationary object	22 Energy loss
3 Length of moving object	23 Substance loss
4 Length of stationary object	24 Information loss
5 Area of moving object	25 Waste of time
6 Area of stationary object	26 Quantity of a substance
7 Volume of moving object	27 Reliability
8 Volume of stationary object	28 Accuracy of measurement
9 Velocity	29 Manufacturing precision
10 Force	30 Harmful action affecting the design
11 Stress or pressure	31 Harmful actions generated by the design project
12 Shape	32 Manufacturability
13 Stability of object’s composition	33 User friendliness
14 Strength	34 Repairability
15 Duration of action generalized by moving object	35 Flexibility
16 Duration of action generalized by stationary object	36 Complexity of design object
17 Temperature	37 Difficulty
18 Brightness	38 Level of automation
19 Energy consumed by moving object	39 Productivity
20 Energy consumed by stationary object	

Table 3. TRIZ 40 design principles

1 Segmentation	21 Rushing through
2 Removal	22 Turning harm into good
3 Local quality	23 Feedback
4 Asymmetry	24 Go between
5 Joining	25 Self-service
6 Universality	26 Copying principle
7 Nesting	27 Inexpensive short life
8 Counterweight	28 Replacement of a mechanical pattern
9 Preliminary counteraction	29 Hydraulic or pneumatic solution
10 Preliminary action	30 Flexible or fine membranes
11 Protection in advance	31 Use of porous materials
12 Equipotentiality	32 Use color
13 Opposite solution	33 Homogeneity
14 Spheroidality	34 Discarding and regenerating parts
15 Dynamism	35 Altering an objects aggregate state
16 Partial or excessive action	36 Use of phase changes
17 Moving to a new dimension	37 Application of thermal expansion
18 Use of mechanical vibrations	38 Using strong oxidation agents
19 Periodic actions	39 Using an inert atmosphere
20 Uninterrupted useful action	40 Using composite materials

from the list of 39 general TRIZ parameters that can be used to describe engineering systems, which ones best capture their design problem. A full list of the 39 parameters is given in Table 2. Next, parameters are used to form a technical contradiction. For the ice maker example the following technical contradiction can be formulated: ‘In an effort to *improve* the quality of the ice and the ice dispensing process (39 Productivity), there is an increase (*worsening effect*) in 17 Temperature and fusion of ice (23 Substance loss).’

In the context of the MBTI model, this step could be said to be most comfortable with individuals whose dominant personalities are (Figure 6):

- introvert
- intuitive
- thinking
- perceiving

Step 3: Determination of corresponding design principles and reviewing and understanding examples showing appropriate application. From the design knowledge found in patents that were examined, Altshuller was able to show that most design solutions could be abstracted to 40 design principles (Table 3). Further, certain generalized technical contradictions would lead to solutions using a few of the design principles. Altshuller

Table 4. Presentation of Design Principle 23 as abstract principle in conjunction with concrete examples to aid in understanding

<p>Design Principle 23: FEEDBACK – Introduce feedback. If feedback is present, change it.</p>	
<p>The diagram shows a cross-section of a dishwasher with numbered parts: 1 (door), 2 (main wash chamber), 3 (upper rack), 4 (lower rack), 5 (spray arm), 6 (spray arm), 7 (door seal), 8 (door handle), 9 (door latch), 10 (drain pump), 11 (drain hose), 12 (Doppler radar sensor), 13 (Doppler radar sensor), 14 (control panel), 15 (control panel), 16 (control panel), 17 (control panel), 18 (door hinge).</p>	<p>Example: Dish washing machine. Developed from [33].</p> <p><i>Design Problem:</i> Dishwashing machines normally use fixed program steps, typically controlled by electronic controllers or electromechanical switching mechanisms. Individual washing cycle steps are always performed in a predetermined manner, irrespective of the operating state of the machine. Unpredictable events occurring during the washing cycle (for example, a blocked spray arm, incorrectly inserted dishes, excessively dirty nozzle, etc) are not accounted for and may result in a poor dishwashing. <i>Design Solution:</i> Doppler radar sensors 12 13 are integrated into the dishwashing machine to feedback the current state of the wash cycle to the electronic controllers. The Doppler radar sensors allow a large number of different functions to be monitored allowing better regulation and control of the dishwashing machine operations. The feedback provided by radar sensors to the electronic controllers on the current state of the washing cycle, allows changes to be made in response to any occurrence of unpredictable events.</p>

developed a contradiction matrix capturing these relationships. For a particular generalized technical contradiction, one can use the matrices to determine the most commonly used design principles.

For the technical contradiction in the current example defined in Step 2, the contradiction matrix recommends design principles 35, 21, 28, 10 and 23. The order presents the most commonly used principle first. The designer can then look up the meaning of the recommended principle and review application examples for better understanding. An example of such a presentation for principle 23 feedback is illustrated in Table 4.

In the context of the MBTI model, this step could be said to be most comfortable with individuals whose dominant personalities are (Fig. 6):

- extrovert
- sensing
- thinking
- judging

Step 4: Application of design principles to concept generation using traditional ideation techniques such as brainstorming. For ice maker example, a re-examination of the EMS model (Fig. 5) reveals the presence of signals emanating from each of the three events that trigger the agitator. The inventor therefore decided that instead of having the agitator independently controlled by three different events, all three events would be monitored and their actions fed back to a single controller that ensured that the agitator did not consecutively activate two or three times. For example, if the timer had just activated the agitator, and ice was dispensed, the controller would ignore the latter action and prevent the agitator from activating twice.

In the context of the MBTI model, this step

could be said to be most comfortable with individuals whose dominant personalities are (Fig. 6):

- introvert
- intuitive
- thinking
- perceiving

Alternatively, looking at the sole use of brainstorming for ideation, the designer goes from problem formulation and clarification directly to concept generation (Fig. 7).

It is important to see these in the context of engineers' work, and their personality types. In a typical set of engineering students, there is a higher percentage of ISTJ (19%) and ESTJ (11%) than any other type, and that there is much more INTJ and INTP types than estimated in the general population [24]. Further, Capretz [24] predicted work related implications of these results as '...NTs are heavily represented in R&D organizations. In most companies NTs will be attracted to areas engaged in major design activities. However, once all of the conceptual work on a project has been done, many NTs prefer to start working on something new... NTs always seem to be looking for new challenges, whereas STs are comfortable with applying previous experience in order to solve new problems; they are realistic, investigative, but conventional.' Given this information, and because TRIZ provides tools for STs to combine conventional approaches to new problems, and for NTs to generate ideas on how TRIZ design principles can be applied to the problem at hand, in comparison to the application of brainstorming as the sole creative problem solving tool, providing TRIZ knowledge might mobilize idea generation by everybody in a design team.

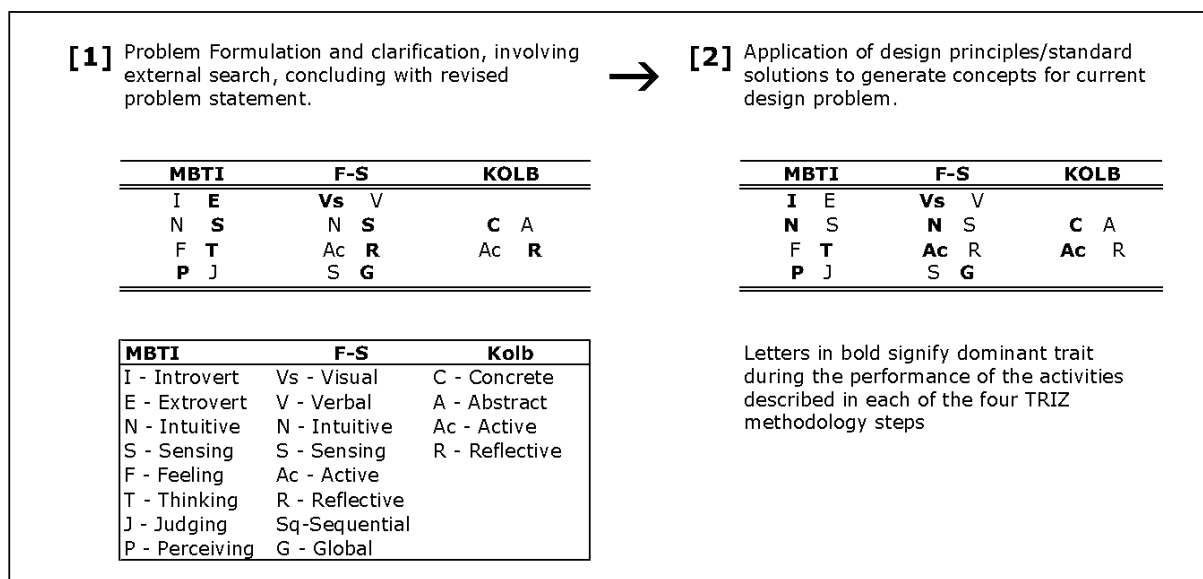


Fig. 7. Dominant learning style dimensions in both general steps of creativity using brainstorming (and its variants) as defined by MBTI, Felder-Silverman and Kolb models.

TRIZ in the context of Felder-Silverman

With reference to Fig. 6, the dominant learning styles can be defined for each of the four steps of the TRIZ-based ideation process. Numerous studies in the literature have found engineering students to be 63% active (implying 37% reflective), 63% sensing, 82% visual and 60% sequential [22]. Use of the TRIZ-based approach alternates between the various sides of the four learning dimensions ensuring that a broader number of students experience a level of comfort during some stage of the ideation process. Brainstorming on the other hand (Fig. 7) is more limiting. For example, both brainstorming steps of problem formulation and concept generation are mainly *visual* and *global*, leading to a level of discomfort during the entire process for *verbal* and *sequential* students, respectively. However the TRIZ-based process, Steps 2 and 3, are primarily *sequential* providing a level of comfort for approximately 60% of engineering students who are visual. In addition, although Step 4 is generally *global*, in the TRIZ context, the reduction of the solution space through restriction to a few design principles creates a sense of ideation in small logical steps that would be appealing to *sequential* students as well. Similarly, Step 2 of the TRIZ method is primarily *verbal* and would appeal to the 18% of the engineering student body who are confronted with an entirely *visual* process using traditional brainstorming.

TRIZ in the context of the Kolb model

Superimposing the four steps of two main TRIZ tools (technical and physical contradictions) over the Kolb model as shown in capital letters in Fig. 8 reveals that the four sequential TRIZ steps loosely follow the Kolb cycle (Fig. 6). The use of TRIZ,

therefore, in conjunction with traditional ideation methods would meet (at one point in the cycle) the learning style preferences of all engineering students whose learning style preferences have been shown to be approximately 10% (quadrant 1: the accomodator), 40% (quadrant 2: the diverger), 30% (quadrant 3: the assimilator) and 20% (quadrant 4: the converger) [35]. In contrast, brainstorming used alone moves from a Type 1 activity (problem clarification) directly to a Type 4 activity (concept generation) as shown in Fig. 5. This approach, on average, only matches the learning styles of about 30% of engineering students. The use of TRIZ in conjunction with traditional creativity methods: (1) cycles the Kolb model suggesting that students will *learn* to become better at ideation, and (2) touches on all learning styles giving each student a certain comfort level during at least one step of the ideation process.

CONCLUDING REMARKS AND IMPLICATIONS FOR ENGINEERING EDUCATION

What is a person's creative potential? Can it be increased, i.e. can a person learn to be more creative? Prof. Carlos Santamarina of Georgia Tech who has written about and studied the teaching of creativity states that, 'There are skills that can be learned . . . every student can be creative, better at problem solving and invention if they are aware of their own creativity and how to improve it' [36]. Can the use of systematic creativity method such as TRIZ increase the creative potential of students? Can their use increase their creative output? To answer these questions, one must demonstrate cause and effect: does a

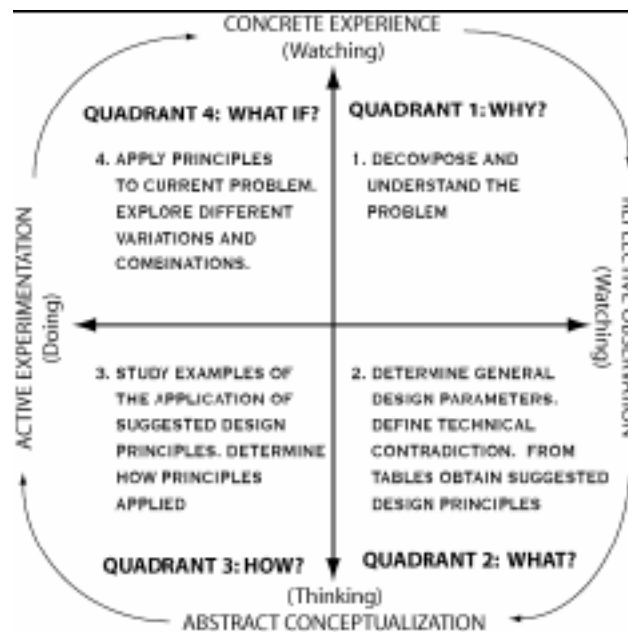


Fig. 8. TRIZ steps for technical contradictions overlaid on the Kolb model of learning.

particular intervention lead to an increase in creative potential and/or creative output? From a learning styles perspective it appears that methods such as TRIZ that match the learning styles preferences of a broader proportion of the student population during their use, as compared to the sole use of traditional methods such as brainstorming, *should* result in an increase in the creative potential and output of the students.

Associations between an increase in comfort level and a rise in creative potential can be found in the literature. For example, a personality instrument that has been used to loosely measure an individual's creative potential is the Herman Brain Dominance Instrument (HBDI). The scores and profiles from using the instrument reveal four different ways of thinking and 'knowing':

- A = analytical-logical-quantitative;
- B = sequential-organized-detailed;
- C = interpersonal-sensory-kinesthetic;
- D = innovative-holistic-conceptual thinking.

A longitudinal study at the University of Toledo conducted on first-year engineering students from 1990–1993, revealed a decrease in the extent of B thinking (corresponding to plug-and-chug problem solving) and a corresponding increase in D thinking (creative) from tests conducted before and after the students went through a newly introduced first-year creative problem solving course [37]. The authors of the study suggest that the shift may have been due to the very plastic nature of the brain that undergoes change with each use, and can therefore result in thinking preferences changes. Preferred thinking modes require less energy in the brain and are usually more enjoyable. Students who enjoyed the design experience in the first-year course may have therefore shifted their thinking preferences to D [37].

This and other studies, such as [38], suggest that an increased level of creative activity in the engineering curriculum with an associated comfort level amongst the students may indeed change the way they think, and thereby increase their *creative potential*. The increase in comfort level of a broader number of students during the ideation phase of the design process through the use of systematic creativity methods such as TRIZ, therefore has the potential to achieve the same.

Does the use of TRIZ increase the creative output of students? A preliminary study was conducted by the authors to measure the creative output of two cohorts of first-year engineering students working on the same design problem, one group using traditional ideation methods and the other also using TRIZ technical contradictions [39]. Brainstorming and TRIZ teams were drawn from three and two sections, respectively, of the course with each section divided into eight, four-person teams. From the study, the authors found that teams exposed to and using TRIZ methods were able to produce an average of 35 unique solutions per section, a 115% increase over non-TRIZ sections that averaged 16.3 unique solutions per section. A comparison of the number of unique feasible concepts produced per team found that TRIZ teams averaged 8.94 feasible concepts per team, a 102% increase over non-TRIZ teams that averaged 4.42 feasible concepts. The authors were able to conclude that the introduction of TRIZ does lead to an increase in *creative output*. What still needs to be investigated, however, is how much of that increase is due to learning style comfort and how much is due to the domain knowledge inherent in TRIZ but absent in brainstorming. Further research will focus on formulating experiments to discern this.

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