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DEVELOPING GUIDELINES FOR PROBLEM SOLVING

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1. Introduction

In this paper, we propose a conceptual framework to explicitly evaluate the completeness of the guidelines for problem solving, with the aim of a better understanding of existing methodologies. Instead of generating new sets of guidelines, it encourages the reuse of previous experience, helping in reorganizing the knowledge from existing methods.
Although the creation of guidelines is a common activity in nowadays design research, there are neither special tools to support their creation nor ontologies to better understand their rationale. Usually, the creation of a set of guidelines is based on the experience of the creator; starting from practical examples, he/she extrapolates and generalizes various strategies of intervention, building guidelines that can be used in different contexts. This activity is quite free and the completeness and effectiveness of the resulted set of guidelines is strictly dependent on the personal skills of the creator. In improving an existing set of guidelines, a well-defined structure may help in identifying lacks and shortcomings, increasing completeness and consistency.
A guideline for problem solving should serve a reader as source of inspiration. The guideline's influence on the reader may occur in a systematic way, when designers actively search for inspiration, or even unconsciously or by chance [Goldschmidt and Sever 2011]. Gonçalves et al. [2013] tried to understand which kind of idea-generation method is preferred by designers, while Chulvi et al. [2012] studied the differences on design outcomes. An important group of triggers for design are represented by visual stimuli, and their impact on design was explored by several authors [van der Lugt 2005], [Goldschmidt and Smolkov 2006], finding a general positive effect on creativity. The synergic effect of a combination of textual and visual stimuli on learning has been confirmed by Schnotz [2002], while the effect of the representation of stimuli in problem solving has been addressed by Sarkar and Chakrabarti [2008].
The use of text as stimuli for idea generation was promoted by several researchers. Between them, Goldschmidt and Sever [2011] explained a positive effect of textual stimuli on originality, but they mentioned no effect in "practicality". Chiu and Shu [2012] studied the effect of verbs as stimuli for idea generation, finding a general increment in creativity. With a different prospective, Fantoni et al. [2007] started from a functional description of products to obtain a new design method, based on the analysis of functional synonyms and antonyms.
Alongside purely linguistic methods for idea-generation, there are several more structured methods, which provide complex guidelines or checklists. In this class of stimuli it is difficult to make overall considerations due to the big number of factors involved. However, these methods are largely used in industry and their effectiveness has been proved in several case studies.
Among them, there are highly free methods, such as the checklist of Osborn [1953], elaborated by Eberle [1972] with the name of SCAMPER (acronym of Substitute-Combine-Adapt-Modify-Put to

other use-Eliminate-Reverse); and there are strictly guided methods, such as the 76 standard solutions [Altshuller 1986], Synectics [Gordon 1961], ASIT (Advanced Systematic Inventive Thinking) [Horowitz 1999], [Turner 2008], and many others [Smith 1998].
The use of models, schemas, or merely external representations is a useful support for design in general. There are several reasoning schema for design, such as function-behaviour-state [Umeda and Tomiyama 1995], TOP model, Energy-Material-Signal model [Rodenacker 1971] and others. Although there are many of them, they are concentrated on the analysis phase, and they rarely support guidelines for idea-generation; moreover, just a few of them allow a graphical representation of the solutions. Among the latter, the Su-field model [Altshuller 1984] has been used to support the 76 standard solutions; the Energy-Material-Signal (EMS) has been used for a set of compacted standards [Ogot 2004], [Ogot and Kremer 2004], [Orloff 2006], and TRIZ functional analysis has been used along with some guidelines of "Oxford Creativity", to facilitate "trimming" [Gadd 2011]. Furthermore, a graphical representation of the solution is useful to reduce the cognitive load and facilitate the memorization of a guideline.
This paper is structured as follows. In section 2, a brief discussion on the basic features of a guideline for problem solving will be presented. In section 3, the authors argue on the influence of the type of problem on the effectiveness of a special set of guideline. In section 4, the proposed structure for the guideline evaluation is illustrated. Finally, in section 5, a case study on the reorganization and improvement of the 76 standard solutions is reported.

2. Basic features of a guideline

As part of the innovation process, problem solving is surely a very important activity. It was defined by Anderson [2009] as "any goal-directed sequence of operations", while Jonassen [2000] described a problem as "an unknown entity in some situation (the difference between a goal state and a current state)". Although there is little agreement on the cognitive processes of problem solving, Jonassen [2000] highlighted two necessary attributes. First, problem solving requires the mental representation of the problem, known as problem space [Newell and Simon 1972]. Second, problem solving requires some activity-based manipulation of problem space, be it an internal representation or an external physical representation [Jonassen 2000].
Since a problem can be defined as the difference between a goal state and a current state [Jonassen 2000], there will be no problem space without discrepancies between "what I want" and "what I have". Furthermore, there will not be a problem solving process without a manipulation of the problem space. A guideline may influence the mental representation of current state and goal state, as well as the transition from current state to goal state. Thus, the authors have defined three space of intervention.

- Goal state: a guideline acting on the goal state identifies, defines or changes goals. Typical guidelines acting on the goal state are "What if you combined purposes or objectives?" or "Define the desired action". Thus, designers are stimulated on generating or identifying objectives.
- Current state: a guideline acting on the current state identifies new entities or attributes of entities to make designers aware of their existence. Typical guidelines acting on the current state are "What can be blended, mixed, or included?" or "Define the problem objects". In these cases, designers are stimulated on generating or identifying entities.
- Transition current state->goal state: a guideline acting on the transition from current state to goal state describes how the goal state can be achieved through the manipulation of known entities of the current state. A typical guidelines acting on this transition is "imagine the object performing the wanted action". Thus, designers are stimulated on using entities already present in the current state to reach a goal state.

In order to find a solution, a guideline explicitly or implicitly provokes the match between current state and goal state.
A minimal guideline can be a "trigger word", where a verb, adjective, concrete or abstract nouns can be provided (such as "modify", "length", "pen" or "high"). An example of this type of guideline is a method for idea-generation tested by Chiu et al. [2007] and named "Trigger Verbs". It consists in the generation of verbs, related or oppositely-related to the functional description of the problem. Chiu

and Shu discussed about the effectiveness of different types of verbs, providing some considerations: lower level (more specific) verbs are more effective, while higher level general verbs are used successfully in conjunction with lower verbs [Chiu et al. 2007]; intransitive verbs are less likely to be used successfully in the development of concepts [Chiu et al. 2007]; verbs similar to the functional description of the problem are less effective than verbs oppositely related with the functional description of the problem [Chiu and Shu 2008]. In order to explain this last sentence, it seems that an increased level of novelty, granted by opposite verbs, may be due to the introduction of new entities; not directly related to the problem, but recalled from designer's memory [Chiu and Shu 2008]. We can say that "Trigger verbs", and more generally "trigger words", can help designers to generate solution without explicitly guide the ideation process.

A more detailed guideline can be provided in the form of Verb-Object, without specifying particular features (such as "modify the pen"); it can specify the objectives (such as "Imagine the pen performing the wanted action"); and it may suggest specific feature or a way to do what you need (such as "Modify the shape of the pen to perform the wanted action" or "Modify the pen to perform the wanted action, adding a substance inside the pen").

Some methods, such as SCAMPER, help in finding new entities of the current state and the goal state. They stimulate the creation of new entities, the identification of hidden entities and the elaboration of different objectives through questions (such as "What else is like your product?"). They do not provide sentences in the form of "do this to obtain this"; thus, the transition from current state to goal state is not explicitly guided and it is left to the cognitive process of the designer. Other methods, such as ASIT, guide the designer throughout all the ideation process, from goal state and current state definition to the transition from current state to goal state.

It is not clear if a very detailed guideline is better than a simple one. Some authors tried to understand how the type of method affect the design outcomes; for instance, Ramos and Escrig [2012] compared brainstorming, SCAMPER and Functional Analysis, finding that "intuitive methods provide more novel outcomes, while the most useful outcomes are achieved with the use of more structured methods". Probably, a very detailed guideline may help in avoiding ambiguities, but it can lead to design fixation [Jansson and Smith 1991]. Furthermore, a detailed guideline can increase the complexity of the guideline itself while a less detailed one may not contain the necessary knowledge to solve the problem. The authors agree that a complete and effective guideline should be able to explicitly guide the entire ideation process.

3. A special set of guidelines for each type of problem

After many studies about a general schema for problem solving, many authors seem to agree that effectiveness of schemas for problem solving depends on the type of problem [Jonassen 2000], and although there are methods which can be used more frequently than others [Lin and Hong 2006], each type of problem should have its customized set of guidelines, and a set of guidelines is more or less effective depending on the type of problem to be solved.

According to Jonassen [2000] definition of problem, a problem exists if there is a difference between "what I want" and "what I have". Initial state and main goal can be used to define the conditions that limit the use of a set of guidelines.

For example, the 76 standard solutions use "If-Then" conditions to identify the type of problem, and they are expressed in one or more sentences, such as "If there is a SFM (Su-Field model) which is not easy to change as required…". The first part identifies the SFM as the involved entity in the problem. The second part specifies a transformation, i.e. a required change on the SFM. In this way, initial state and main goal are respectively defined as "a SFM" and "a modified SFM". Generalizing this approach, the identification of the problem can be obtained defining the necessary entities for the existence of a problem and their required transformations.

Other methods do not explicitly mention a condition; however, some conditions are implicitly present. For instance, a quite intuitive method such as SCAMPER cannot be applied if there is not a product to improve. Thus, the existence of a product and the need to improve it are necessary conditions for the application of the method.

In the authors' opinion, the initial state and the main goal should be explicitly clear. For each type of problem there can be different guidelines, but the structure with which they are suggested can be always the same. This structure is presented in the following section.

4. Structuring guidelines for problem solving

A framework to systematically structure a set of guidelines has been extrapolated from the discussion of the first three sections and is shown in Figure 1. The attempt of the authors reflects the willingness to synergically use what can be deduced from a logical point of view (Sub-goals) with what can be derived only by experience (Suggestions).

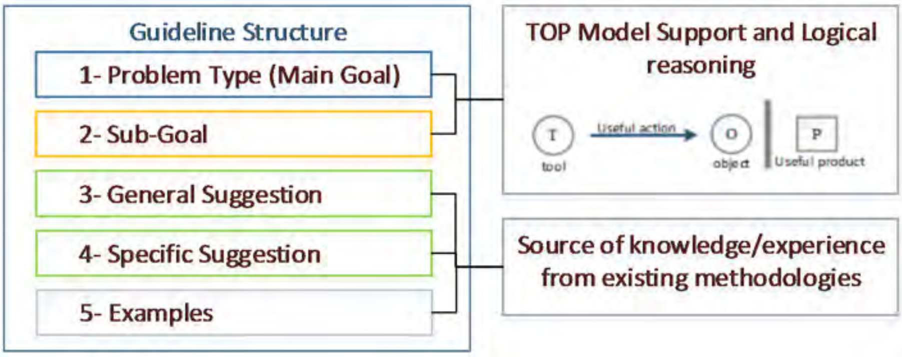

Figure 1. The structure of a guideline for problem solving

Problem Type

When a set of guidelines is being analyzed, we must understand the necessary conditions to use it. Accordingly, the first box represents the identification of the problem, i.e. the identification of the initial state and the main goal. If the problem type is not explicitly defined, we can use the TOP model [Royzen 1999] to identify the problem. A TOP model can represent a problematic situation (see Figure 2) and can be easily adapted to symbolically represent solutions. By using a model, the initial state is well defined and the identification of the problem is more intuitive.
Practically, the TOP model limits the boundaries of applicability to problems that can be described with an Action, a Tool (substance that generates the Action), an Object (substance that is subjected to the Action) and a Product (substance that is generated from the object after the application of the Action). I.e., the model visually describes a sentence such as "T acts on O obtaining P".

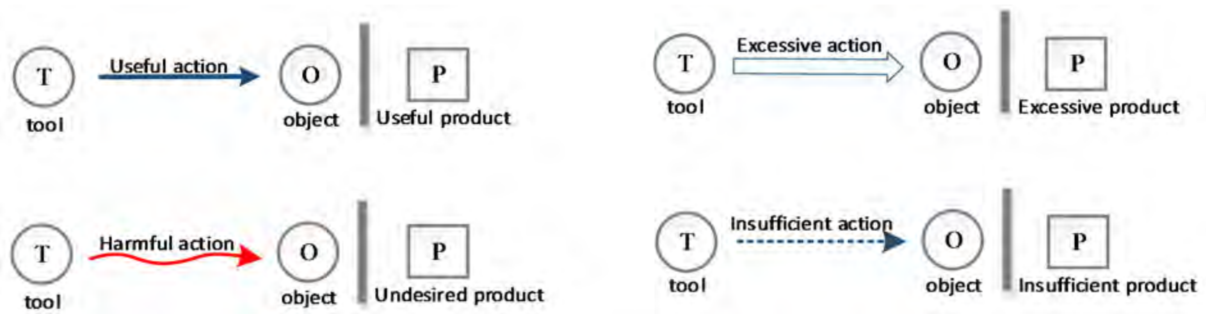

Figure 2. Identifying problems with TOP model

Depending on the type of product, TOP model can describe three types of problem:

- Excessive action (when the product of the action is excessive)
- Insufficient action (when the product of the action is insufficient)
- Harmful action (when the product of the action is undesired)

These problems are related with an explicit main goal:

- Excessive action->I want to reduce the product of an action

- Insufficient action->I want to increase the product of an action
- Harmful action->I want to avoid the undesired product of an action

Actually, TOP model may be used to describe problems of missing actions, but this is not discussed on this paper. Thanks to the identification of a problematic TOP model, the initial state (in the form of necessary entities for the existence of the problem) and the main goal of each problem are clearly defined.

Sub-Goals

The second box of figure 1 represents the Sub-goals of the identified problem. SubGoals are defined as an elaboration of the main goal and represent feasible conceptual solutions to the given problem. They are valuable alternatives that can be found through a better understanding of the goals or a cause-effect analysis on the identified problem. Thus, the subgoals are a more precise way to describe “what I want” and can be interpreted as an elaboration of the goal state.

A simple cause-effect analysis has been performed to understand necessary and sufficient changes to solve the problem. When dealing with harmful actions, the main goal is “avoiding the generation of the undesired product”, thus, there can be several logical Sub-goals:

- Prevent the action to be generated -> **make** the tool **unable** to produce the harmful action;
- Prevent the action to propagate -> **block** the harmful action or **deflect** the harmful action;
- Prevent the action to produce the undesired product -> **make** the object **insensitive** to the harmful action;
- Prevent the product to be harmful -> **make** the product **useful** or not harmful.

For insufficient action, the main goal is “increasing the product of an action”:

- Improve the generation of the action -> **make** the tool **more effective** on producing the action;
- Improve the propagation of the action -> **enhance** the action;
- Improve the effect of the action -> **make** the object **more sensitive** to the action;
- Improve the insufficient product -> **make** the product **sufficient**.

For excessive effect, the main goal is “reducing the product of an action”:

- Reduce the generation of the action -> **make** the tool **less effective** on producing the action;
- Reduce the propagation of the action -> **reduce** the action;
- Reduce the effect of the action -> **make** the object **less sensitive** to the action;
- Reduce the excessive product -> **make** the product **sufficient**.

Using the TOP model, the Sub-goals can be supported by a symbolic representation, reducing cognitive load and facilitating memorization.

Suggestions

Suggestions (third and fourth boxes of Figure 1) explain the feasible manipulations of the current state. The main difference between a Sub-goal and a Suggestion is that a Suggestion is not a conceptual solution, but merely a possible change of the current situation. While a Sub-goal logically follows from the type of problem, a suggestion can statistically or intuitively help in solving a problem. For instance, if we want to increase the acceleration of a body, we can use the Newton’s formula $F = ma$ to define two Sub-goals: “reduce the mass of the body without changing the force” and “increase the force without changing the mass of the body”. These are directly and logically related to the main goal of increasing the acceleration of the body. Instead, a suggestion can be “reduce the volume of the body” or “change the temperature of the air”, which are not logically related to an increased acceleration of the body, but they may work as triggers for a practical solution.

Suggestions explain manipulation of the current state: i.e., manipulation of the problematic TOP model.

In order to manage a big number of suggestions they are grouped in General Suggestions. A General Suggestion takes the form of verb and object, in order to identify all the operations that can be performed on the elements of the problem, such as “modify a substance”, “add a substance”, “merge a substance with another substance” and so on.

Each General Suggestion is supported by a group of Specific Suggestions. A Specific Suggestion answers to the question “how can I carry out the General Suggestion?”. Thus, for the General Suggestion “modify substance”, the Specific Suggestions will reveal some ways of “modifying a substance”, such as “divide the substance in more parts”, “make the substance flexible” or “change the form of the substance”.
Since the Suggestions are simply triggers, their content may be filled with every source of knowledge; in the case study of the next section, this knowledge has been taken from the 76 standard solutions.

5. Case study: improving the 76 standard solutions

The 76 standard solutions are one of the most used tools of the well-known theory of inventive problem solving. They were created by G. Altshuller between 1975 and 1985 as solutions for common inventive problems extracted from the studies of patents and they are organized in five classes: “Composition and decomposition of SFMs”, “Evolution of SFMs”, “Transitions to supersystem and microlevel”, “Measurement and detection standards” and “Helpers”.
A standard (Figure 3) can be identified with its class, subclass and body. With the exception of the class "measurement and detection standards", all classes and subclasses are named in accordance with the type of solution they lead. So, they can be considered as suggestions for the solution. The body of a standard contains a first condition to identify a main goal and/or an initial state. A second condition and eventually a third one are used to identify the constraints of the problem. The rest of the body contains Suggestions for the solution, other goals, some examples, a graphical representation of the initial state and a graphical representation of the solution.

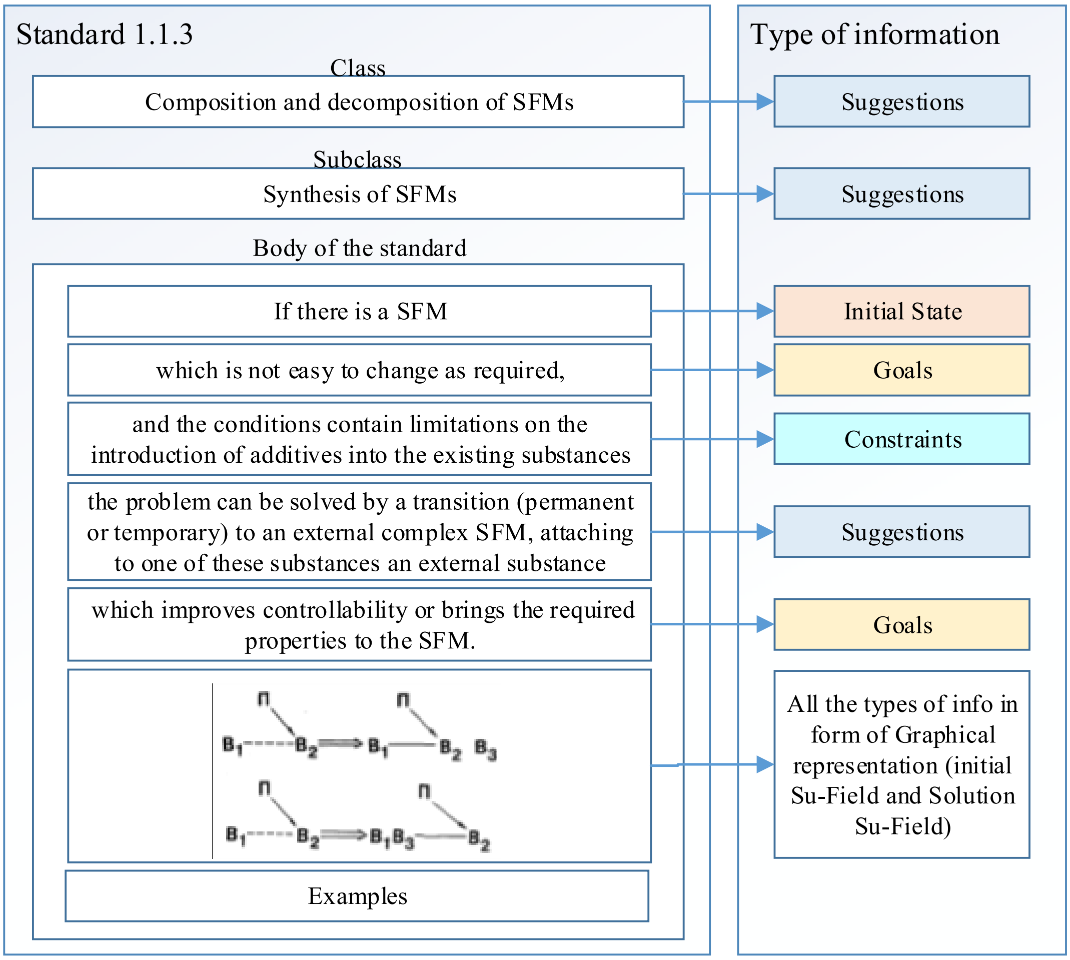

Figure 3. Structure of a standard solution; in the left column the standard 1.1.3 is reported

As we can see in figure 3, where a standard has been analyzed, the information contained in the 76 standard solutions is fragmented and complicated. Consequently, interpretation and reading of a standard are difficult. The use of a standard is given in accordance with the initial conditions, which are expressed as if <condition> then. Many authors have proposed approaches to simplify the application of standards, proposing external schemas based on a functional diagram. However, many difficulties have been reported to organize all the information contained in the original system and to manage a proper use of the class “Helpers”.
The 76 standard solutions do not contain Sub-goals, and the identification of the problem is not adapted for a functional approach. For this reason, the 76 standard solutions can be ameliorated with the new proposed structure, using the TOP model to identify the problem and the Sub-goals to improve efficacy, clarify objectives and possibly increasing the paths for the solution.
The 76 standard solutions exploit the substance-field ontology, which is composed of two main concepts: substance and field [Bultey et al. 2007]. Thus, we can extrapolate four types of General Suggestions: “add a new substance”, “add a new field”, “modify a substance” and “modify a field”.
Since Tool and Object of the TOP model can be considered as substances, the General Suggestions can be easily introduced in the proposed structure. Thus, the General Suggestions and the Sub-goals are combined to form an almost complete guideline. From a logical point of view, some General Suggestions cannot be associated with all the Sub-goals; consequently, each Sub-goal is supported by a maximum of three General Suggestions. The resulted Sub-goals and their General Suggestions for a problem of harmful action are reported in Figure 4.

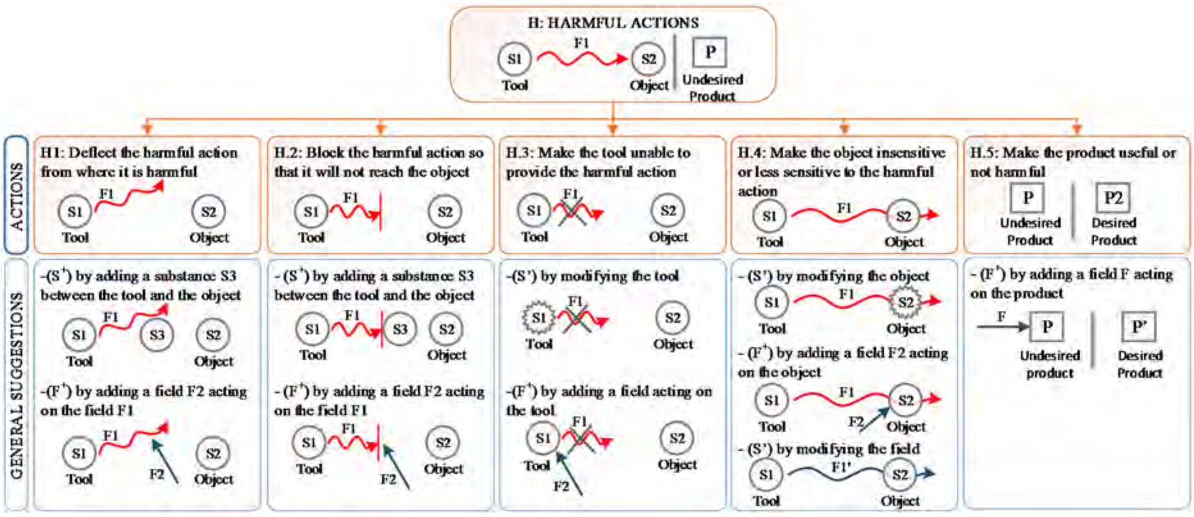

Figure 4. Sub-goals and General Suggestions for a problem of harmful actions

Each General Suggestion can be supported by one or more Specific Suggestions, which answer to the question “how can I carry out the General Suggestion?”. Thus, extrapolating the knowledge from the 76 standard solutions, selecting the feasible Specific Suggestions for each General Suggestion (see the example of figure 5) we filled the fourth part of the guideline.

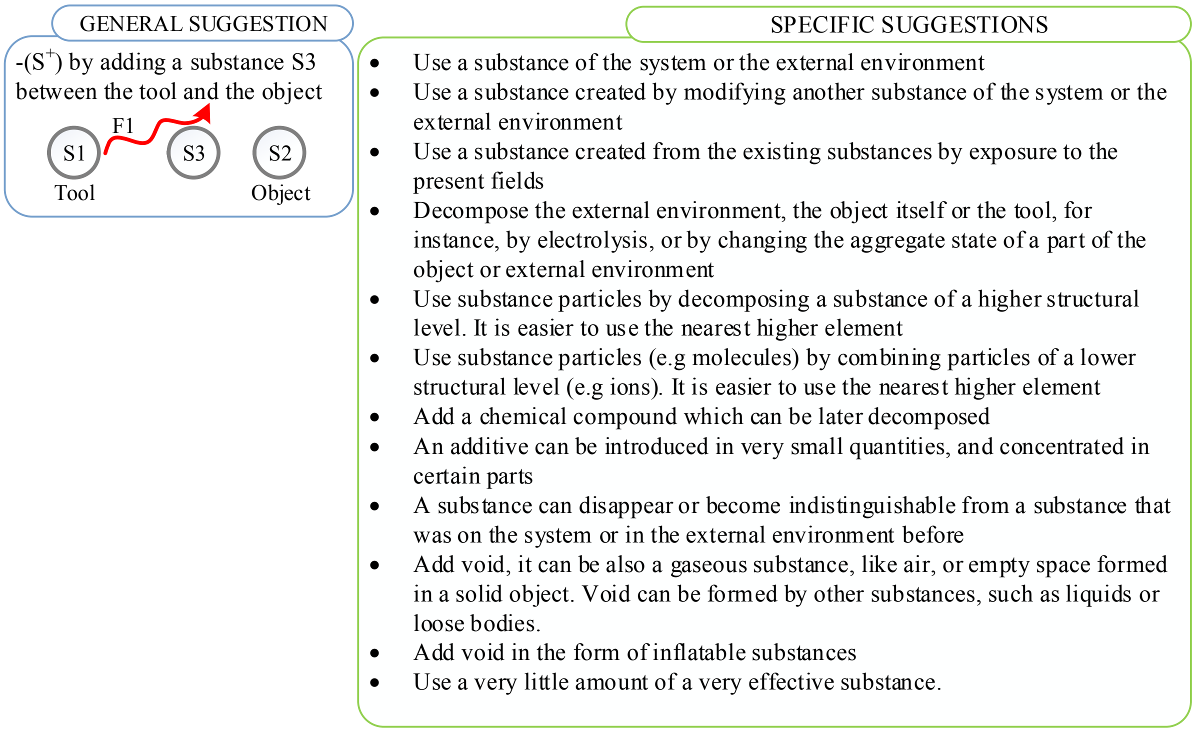

Figure 5. Specific Suggestions for the General Suggestions "Add a new substance" extrapolated and reorganized from the 76 standard solutions

Finally, a Sub-goal, a General Suggestion and a Specific Suggestion can be supported by an example. An example can be taken from patents or from the everyday life, and it is presented with natural language and images.

Eventually, since a guideline is a composition of more parts, it can be presented with a flexible structure: for a selected problem, there are several Sub-goals, for a selected Sub-goal there can be several General Suggestions and so on. In Figure 6 a complete guideline is reported as a combination of hints of different levels of detail. In this way, the user has a comprehensive overview of the feasible Sub-goals and he can choose the most appropriate path to solve the problem. Moreover, he can use the Suggestions to get more knowledge or triggers.

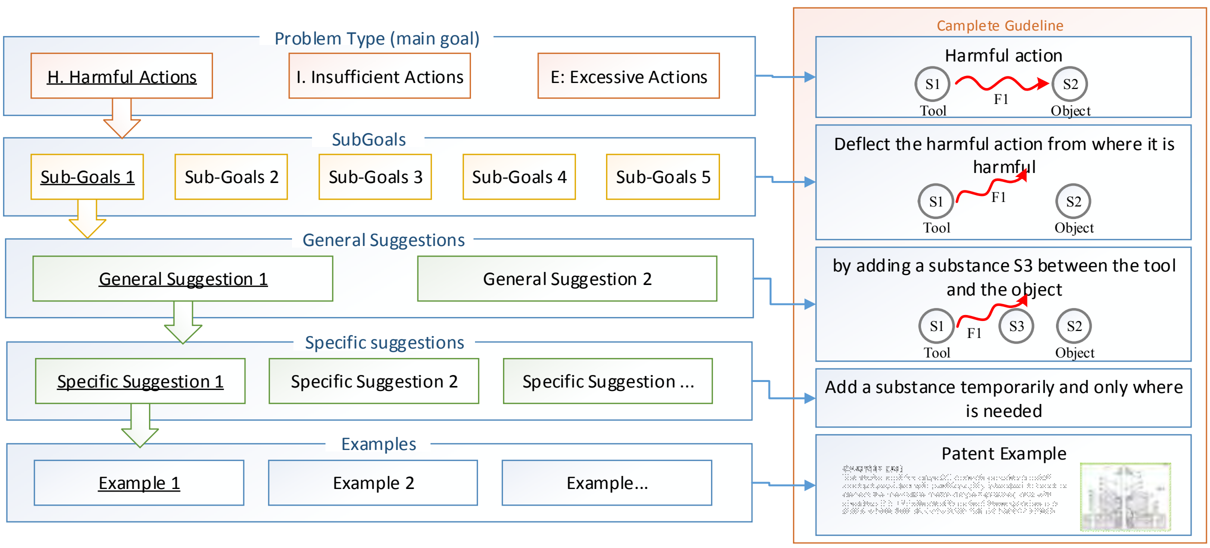

Figure 6. Guidelines as a combination of hints at different level of detail

6. Conclusions

Guidelines for problem solving are a well-known method to improve creativity in a problem solving activity. In this paper, we have proposed a conceptual framework to explicitly evaluate the completeness of the guidelines for problem solving, with the aim of a better understanding of existing methodologies.

The proposed template is composed of five parts: problem type, Sub-goal, General Suggestion, Specific Suggestion and Example. Thanks to a template of comparison, a method can be studied to highlight shortcomings and identify where it can be improved. In addition, as in the case of the 76 standard solutions, there can be confusion in the structure of a guideline which can be the source of many difficulties of interpretation. Thus, the 76 standard solutions have been deconstructed and reorganized in accordance with the proposed template. The missing parts have been completed with the introduction of two features: the TOP model for the choice of the main goal and the logical actions (Sub-goals) related to the problematic TOP model. The rest is mere an elaboration of the information already contained in the original set of guidelines. The resulted guidelines are clearly more consistent and complete.

The revised method has been proposed to TRIZ experts, obtaining encouraging feedback about the new structure and especially appreciating the idea of an optimized structure to organize and complete a guideline. A more extensive testing has been proposed to non-expert of TRIZ, but the results will be presented in detail in future publications.

The proposed structure resulted to be a valuable tool to reorganize the knowledge of existing methodologies, at least to simplify complex and articulated guidelines such as the 76 standard solutions. It has general validity, because the same process can be used with every method, and instead of generating new sets of guidelines, it encourages the reuse of previous experience.

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