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# Teaching Students to Structure Engineering Problems with CAI Tools*

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The importance of methodologies and computer-aided tools for problem structuring and solving has been demonstrated by various research activities since the 1970s. The need for systematizing the first phase of problem solving activity has led the authors to the development of a dedicated procedure for problem reformulation and the implementation of a dedicated software package, named BOB-UP®. It aims at driving the user to reformulate the initial problem using a dialogue–based system hiding an accurate cause-effect analysis. BOB-UP® provides three tools (Ill-Balls diagram, Fight diagram, and a linguistic composer) that guide step-by-step the user to the right problem formulation. This paper presents the experimentation of such CAI tool within two courses at the University of Bergamo. The first is a compulsory course for the master degree in Mechanical Engineering, while the latter is an elective course for the master degree in Mechanical Engineering and Management Engineering. The experimentation has been carried out with 56 students sub-divided into three groups according to their competences on problem structuring and solving and technical background. We considered five problems related to industrial applications coming from different technological domains to demonstrate the independence of the results from the specific industrial area. Finally, results are discussed presenting advantages and drawbacks. They have been evaluated according to specific criteria to evaluate its usability and efficacy; in addition, students were asked to fill a questionnaire to comprehend the perception they have on BOB-UP® usefulness and potential.

**Keywords:** engineering education; problem structuring; cause-effect analysis; CAI tools; TRIZ; BOB-UP®

## 1. Introduction

During last years, innovation has been one of the key issues to compete on the market. Companies have to develop products and processes shortening times, reducing costs and, in the meantime, ensuring quality and performances of high level. This can be done with the adoption of methodologies, such as DfX, QFD and FMEA, and computer-aided tools, such as CAD, CAM and CAE. Among them, both large companies and SMEs are putting particular attention on systematic innovation methodologies and Computer Aided Innovation—CAI tools.

In such a context, a correct problem definition is of greater importance [1, 2] to find a better solution, as also highlighted by the famous Dewey's citation "A problem well put is half-solved" [3]. In fact, it has been proven that a low accuracy in setup or an insufficient attention during problem structuring [1] may affect the accuracy of the final solution [2]; while a properly stated problem is virtually solved [3], especially for "ill-defined" problems. This emphasizes the need of methods and tools to support this task.

The introduction of mentioned methodologies and tools requires skilled people with specific competences and the capability to face problems in a creative way and with a multidisciplinary approach.

The role of engineering education can play a meaningful role. At present, the curricula of engineering students are structured into rigid compartments, and, in general, competences on IT tools (e.g. CAX tools) and related methodologies are provided. However, few are the competences on methodologies and computer-aided tools for creative thinking management and problem structuring.

The goal of the authors has been to complete the education of engineering students providing specific abilities in such fields through the use of CAI tools and, in this case, with a focus on problem structuring.

Since the 1970s, many efforts have been made to improve problem assessment, managing problem information and avoiding psychological barriers. Studies have been focused on overcoming trivial points of view and to systematize the abstraction of the initial situation by using theoretical models as functional models and cause-effect analysis. Taking into account previous experiences on problem solving techniques, especially root cause analysis and TRIZ, the authors has developed a CAI tool, named BOB-UP®, which guides step-by-step designers during the correct reformulation of the initial problem. Its aim is to reformulate technical problems turning an ill-defined initial problem into a well-defined final problem.

This paper presents BOB-UP® and the results of its experimentation within two courses for the master degree in Mechanical or Management Engi-



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neering at the University of Bergamo. After an overview of related works, BOB-UP® and computer-aided tools made available to the users are introduced. Then, the experimentation phase is described mentioning which and how many students participated to BOB-UP® evaluation, test cases, and how tests have been carried out. Finally, results are discussed presenting advantages and drawbacks.

## 2. Related works

Among methodologies and techniques to approach a problem [4–10], cause-effect analysis is one of the most powerful and well known way to describe how a system works [11] or how it should works and/or why it doesn't work. Various methodologies, such as Failure Mode and Effect Analysis (FMEA) [12], Theory of Constraints (TOC) [13], Ishikawa diagrams [14], Kepner-Tregoe approach [15], Why-Why diagram [16], are based on cause-effect relationships. However, classical cause-effect analysis does not always generate repeatable results due to its dependence on user's skills [17]. Furthermore, there is a lack of interface with problem solving tools, so it can be unclear how to deal with the resulting diagrams [18], and the level of the analysis [11]. The risk is to perform a too detailed analysis with a waste of time and resources, or too superficially, resulting ineffective in the core problem identification.

Also in TRIZ [19], considered by many designers the most complete and powerful method for problem solving [20], the cause-effect approach is widely used to analyse a problem. Problem Flow Network [21], Root Conflict Analysis [18], General Theory of Innovation [22] are some example of tools based on cause-effect relationships for problems analysis. These techniques constitute an improvement if compared with classical cause-effect analysis mainly as far as concerns the interface with problem solving tools; however, their efficiency is too still connected to the user's skill. These tools don't lead step-by-step the users toward a unique problem formulation and there are no indications about the level of detail by which performing the analysis. The lack of ontology, especially about a proper definition of the harm, pushes towards divergent results.

All these reasons can cause different problem interpretations with different (and often wrong) problems to be solved. Furthermore, during the problem structuring phase, designers feel comfortable working with sketches or physical models rather than with formal definition of the problem [23]. Sketching is a spontaneous attitude both to clarify existing idea and to develop new ones [24]. In most cases it can appreciably contribute to define the correct design space [25]. On the contrary, traditional cause effect analysis is conceived as classical text based approach.

To conclude, in literature, experiences and effective results about the introduction of problem solving methodologies (some examples are presented in [26–28]), and related CAI tools [29, 30] within engineering courses are reported, but they did not specifically focused the attention on the issue of problem structuring.

Therefore, for above-mentioned reasons, there is the need of a procedure, which leads users more strictly and contains dedicated tool to guide users toward a right level of detail, without limiting his/her creativity, for performing a correct problem inquiry. Only in this way it is possible to find the problem's exact space-time coordinates, which guide to a unique and systematic problem formulation.

## 3. BOB-UP® CAI tool

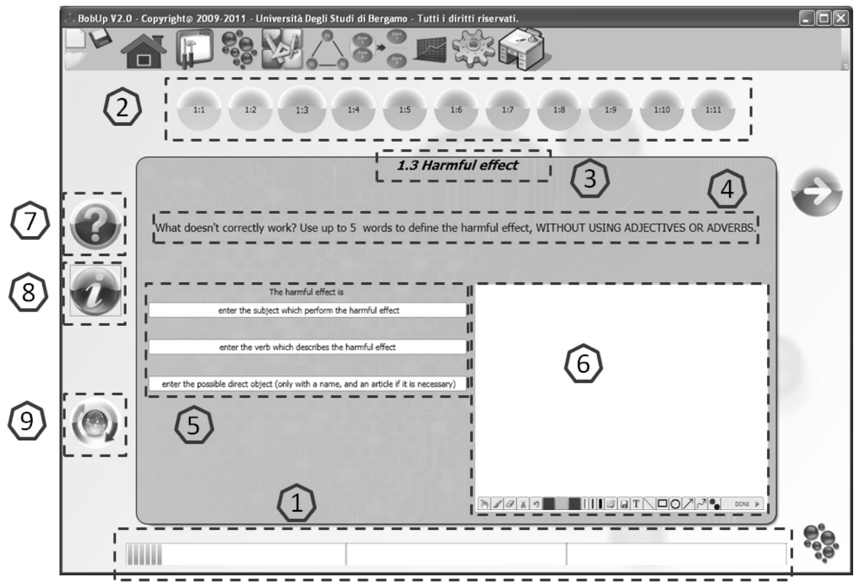
The above-mentioned need has led the authors to develop a procedure for problem reformulation and to implement a dedicated software package, named BOB-UP®. This procedure aims at driving the user to reformulate the initial problem using a dialogue–based system hiding an accurate cause-effect analysis. The authors' goal is to provide a framework enough rigid to converge on a unique reformulation but at the same time avoiding psychological barriers.

Ontology has been set to support all steps of the guided procedure. In addition, grammar rules lead the user to a convergent compilation. An example is the prohibition of using adjectives during the negative effect assessment for emphasizing functional representation and avoiding any subjectivity.

Using BOB-UP®, the users fix progressively, at different levels of detail, the damaged element (i.e. the element receiving the undesired effect), the zone where the undesired effect precisely occurs (i.e. the zone where the damage is more serious), the physical reasons why this harm occurs, and finally the element that causes the harm.

The peculiarity of this approach is that the physical interpretation of the phenomenon/a, which leads to the undesired effect, is not free. It has to be done adopting a reference model of representation and conducted only in the zone where the damage is more serious and in the precise instant when the harm appears.

For the full effectiveness of considered cause-effect approach, it is also necessary to visualize it with a clear picture from different perspectives. In fact, a set of related sketches can stimulate visual




*LEGEND:*
1 – Progress Bar to monitor current step execution
2 – Sub-steps list of current step
3 – Title of running sub-step
4 – Sub-step task: Description of sub-step aim
5 – Form for linguistic description
6 – Graphic area where to draw sketches and/or load images
7 – Help and Tutorials
8 – Advice button to get compilation rules
9 – Update button to migrate changes carried in previous sub-steps

**Fig. 1.** BOB-UP®'s user interface.

creativity even during the problem-structuring phase.

Due to the difficulty to adopt such an approach, dedicated CAI tools are provided to support the users at each step. Filling phase consists in a textual space, which is mainly composed in automatic way according to previous formulation steps, and in a sketching space used for monitoring in real time the detail level of the problem.

To make easier the procedure, linguistic rules are integrated into the textual form and, as mentioned, sketches are inserted to describe the problems. This permits to avoid an overload of visual-spatial working memory and simulate the generation of the greatest number of associations with the minimum of information on the given problem. In addition, at each step, tutorials and help tools, which describe scope, definitions, compilation rules and references, are available to the users.

Figure 1 portrays the BOB-UP graphical user interface.

Essentially, BOB-UP® provides three tools:

1. The *Ill-Balls diagram* to identify the damaged element in a well-defined zone;
2. The *Fight diagram*, a graphic tool used by the user to represent the problem physics and translate it into a precise time instant;
3. A *linguistic composer*, always dialogue based, that automatically collects information from previous steps and composes the last formulation of the problem space, still looking only at the harmful effect (the precise zone and involved elements). The sketch completes this reformulation.

Adopting these tools, the user identifies the element, which causes the damage in a precise zone and time, and describes it with sketches and a precise textual formalization.

The output is a textual reformulation of the problem and associated sketches/drawings of the problem.

In the following a description of mentioned tools is provided.

### *3.1 The Ill-Balls diagram and operative zone*

The Ill-Balls diagram is a technique to graphically represent the undesired effect by means of a spatial decomposition of the zone affected by the harmful effect. The considered space is populated with small balls of different colour to represent the different levels of intensity of the harmful effect under analysis. The use of small balls obliges the user to link each zone of the considered element to a different level of intensity of the undesired effect. Therefore, this diagram helps to break the user's psychological barriers, especially those ones, which force him/her to imagine the system as perfectly homogeneous.

As an example, Fig. 2 shows the harmful action and Fig. 3 the Ill-Balls diagram of a burnt slice of bread. The undesired effect is the burning of slices by the bread toaster. When the temperature of the bread overcomes 180°C, the Maillard reaction causes the burning of the slice. By means of Ill-Balls technique, BOB-UP® forces users to change their perspective from a general to a deeper view. The common view to consider burnt all bread slices has to be changed, limiting the problem space only to its surface or parts of it.

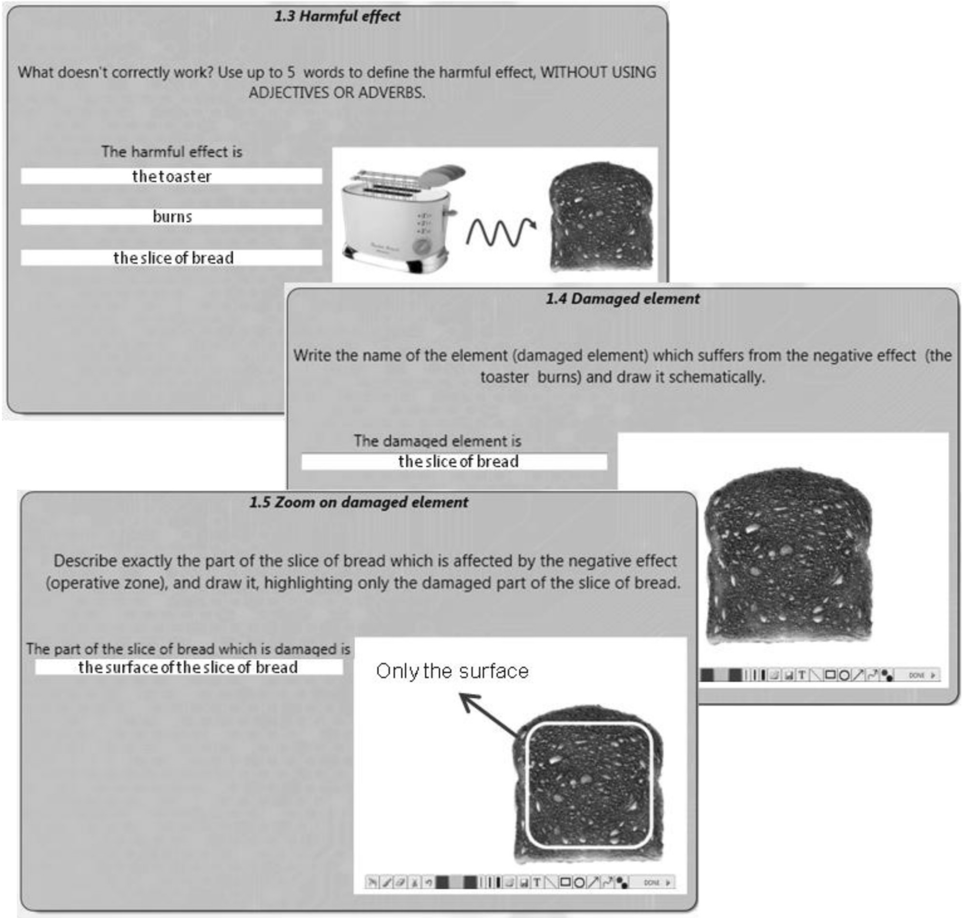



**Fig. 2.** An example of the dialogue based steps to define the harmful action and the damaged element.

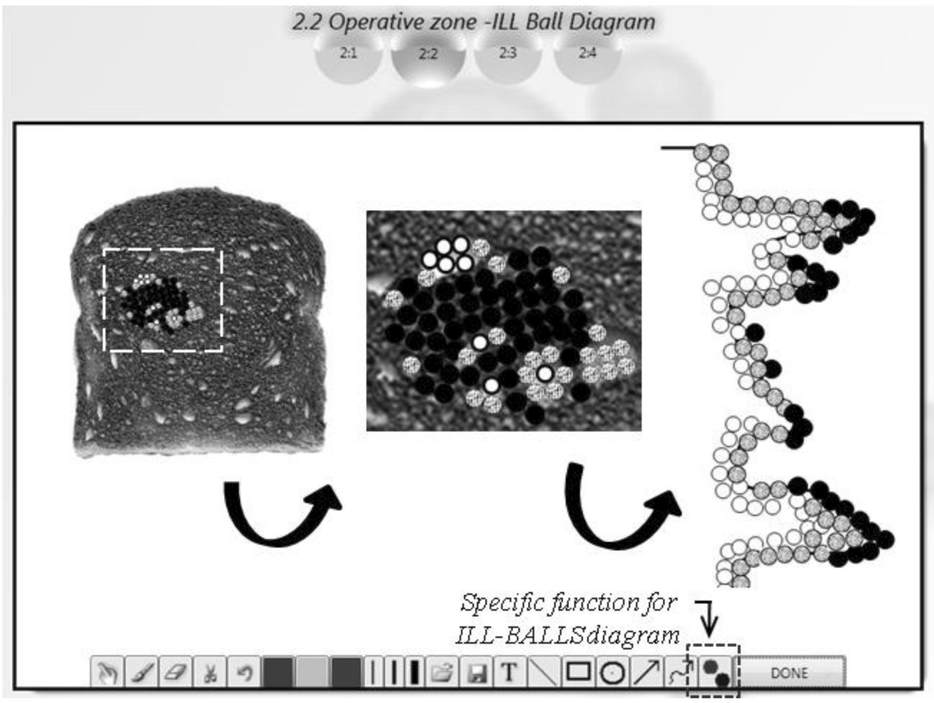



**Fig. 3.** Ill-Balls diagram of a burnt slice of bread.

As shown in Fig. 3, by adding the balls the user is led to move on the bread surface, asking her/himself point-by-point where the burning degree is greater. Thus user's attention is forced towards those parts where the harmful effect is higher, such as the crest of the slice surface.

Apart from placing colored balls on the sketch, the user choices the spatial limits of the undesired effect. As a consequence, user can change rapidly her/his point of view and can narrow the problem space to a very specific area, increasing the detail level by which the problem is described and analysed. The user is so guided to choose the right level to define what really happens and how the undesired effect really acts.

### *3.2 The fight diagram and operative time*

In order to obtain an exhaustive problem definition, the physical interpretation of the problem is conducted by a specific ontology, which permits the user to represent a contraposition of two antagonist systems: the "Negative" and the "Anti-negative" system. In particular they are defined as follows:

- The Negative system is the system, which causes the harmful effect; it is the way by which the parameters of the damaged element are changed in an undesired way.
- The Anti-negative system is the system, which tries to avoid the fulfilment of the Negative system; it is the inertia to every change imposed by the Negative system.

When the Negative system overcomes the Anti-Negative one, the harmful effect arises.

In this way, after the space collocation ("operative zone" defined in the previous steps), the user is able to identify also the time collocation, called "operative time", of the harmful effect. The operative time can be better defined as follows:

> *The instant at which the phenomenon, which leads to the harmful effect, starts into the operative zone.*

As described in [25], space and time analysis cannot be considered independently. In particular, the time collocation is extremely dependent on the space collocation, and the operative time has to be identified into the operative zone previously selected.

To perform such an analysis, BOB-UP® provides the so-called Fight diagram. Fig. 4 shows an example of Fight diagram.

The user generates the Fight diagram describing the Negative and Anti-Negative systems in a Cartesian graph. On the X-axis, the time units are always compared. On the Y-axis, both Negative and Anti-Negative are represented. Force, pressure, energy, and power can be used according to the system conditions. When the cross point appears, operative time is fixed. Cross points indicate the beginning of a

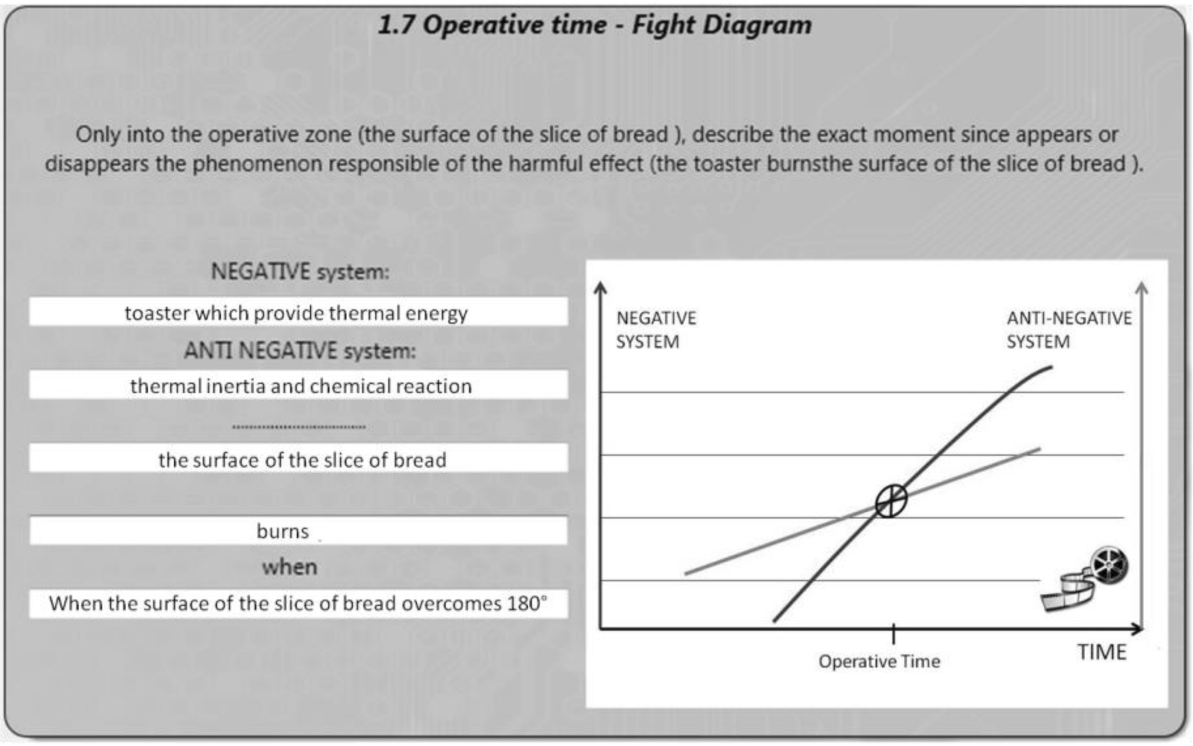



**Fig. 4.** Fight diagram.

new process, which causes harmful effect(s) on the operative zone of the selected element. Any physical problem description has to refer to this operative zone and time.

### *3.3 Procedure to reformulate the problem*

After having carried out the zone and the time analysis of the undesired effect, BOB-UP® drives the user to shift the analysis from the harmful effect to the root cause, i.e. the element(s), which directly provokes considered effect (Fig. 5).

This step differs from the classical cause-effect analysis since the cause we are looking for is the specific element acting on a specific zone (the operative zone) and in a specific time (operative time). So the generic question "Who is causing harms?" used in all cause-effect based methods, is transformed into "What element(s) and, in particular, what part of this element (operative zone of the cause element) causes harms in the specific area at a precise instant?"

In this way, the cause effect chain, composed of the cause element, the harmful effect and the damaged element, is defined and synchronized in time and in space and a more precise understanding of the problem is given.

At the end of the procedure the user has at her/his disposal:

- An automatic problem reformulation containing a zoom on the product with the key elements involved in the problem, i.e., a rigorous definition of the undesired effect and a deep inquiry about critical parts of the element(s) causing harms;
- A physical description of the problem in terms of force/energy and time;
- A set of problem sketches from different perspectives and with different levels of details.

At this stage, the user can use any creative method for idea generation.

## 4. Engineering courses

The authors have introduced competences on problem structuring using CAI tools at the University of Bergamo in two different courses. The first, named "Product and Process Innovation (PPI)", is a compulsory course for the master degree in Mechanical Engineering. It aims at providing a deeper knowledge about systematic innovation, especially TRIZ theory [19] and fundamentals

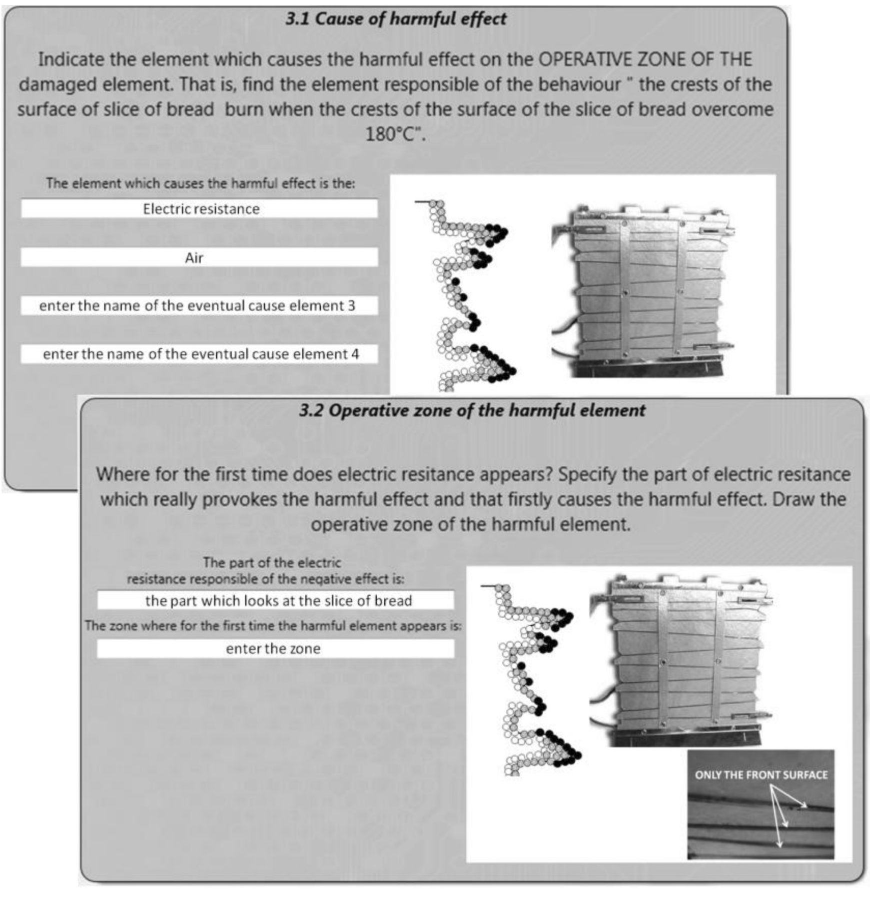



**Fig. 5.** An example of cause's identification steps.

**Table 1.** Courses Features

| | Master Degree | | | | |
|---|---|---|---|---|---|
| **Course** | **Type** | **Year** | **Semester** | **Students [n]** | **Contents** |
| PPI | Mechanical eng. | 1st | 1st | 10–15 | Systematic Innovation and IPM |
| PLM | Mechanical eng.<br>Management eng. | 1st | 2nd | 50–60 | Tools and methodologies for product life-cycle |

about Intellectual Property Management (e.g. Knowledge Management and Patent mining). The basic idea is to provide the students with a structured approach for analyzing product and processes. On average, the class is composed of 10–15 students and the course consists of 8 cfu (university credits) structured in 80 hours, 50% dedicated to practical exercises. The latter, named "Methods and tools for product lifecycle" (i.e., PLM-Product Lifecycle Management), is an elective course for the master degree in Mechanical Engineering and Management Engineering. It aims at providing an overview of computer-aided tools (e.g., CAD, CAE, PDM, ERP) to support the product development process and methodologies (e.g., BPR, DfX and LCA) to manage the whole product lifecycle, from the conception to the disposal. On average, the class is composed of 50–60 students and the course consists of 6 cfu structured in 60 hours, 50% dedicated to practical exercises. Table 1 summarizes courses features.

Both courses require, at different levels of complexity, the development of a project/exercise related to systematic innovation; in particular, it consists in developing autonomously a real case study provided by local companies, both large and SMEs ones. Two different approaches have been adopted. Students of the first course received 40 hours about methodologies on problem structuring and problem solving without the aid of CAI tools and they had to solve 5 test cases. Then, we assigned to each student an industrial case study to be solved with learned methodologies. In the second one, we dedicated 4 hours to introduce BOB-UP® tool and 8 hours to solve selected test cases. In addition, some students work on their own while others in groups.

This permitted us to verify the potential and efficacy of the CAI tool with or without a preliminary introduction to the methodology and with students with different background.

## 5. Experimentation

As mentioned, we have experimented BOB-UP® with the students of two courses in order to demonstrate the methodology efficacy and SW tool usability and friendliness.

### *5.1 Test group*

The proposed CAI tool has been tested with 56 Master Degree students sub-divided into three groups:

1. It comprises 6 Mechanical Engineering students that followed only the PPI course and with a deep knowledge on methodologies for problem structuring and solving;
2. It comprises 6 Mechanical Engineering students that followed both courses with knowledge on both methodologies and proposed CAI tool for problem structuring;
3. It comprises 44 students (both from mechanical and management engineering) that followed only PLM course, and experience only with the CAI tool (no methodology) for problem structuring.

This permitted us to verify the potential of BOB-UP® CAI tool under different conditions and key issues that can have an influence on students' problem solving skills.

### *5.2 Case studies*

We considered 5 problems related to industrial applications coming from different technological domains to demonstrate the independence of the results from the specific industrial area. The test cases were the following ones:

1. Incomplete roller of steel slab, wherein a rolled slab has thickness in the centre less than the thickness near its ends, due to a quicker cooling of the ends.
2. Loss of water from valves of water bottle caps, wherein under determined condition a new type of suction valve doesn't retain the water contained into the bottle.
3. Slice of bread burnt by a toaster.
4. Ultrasonic welding of ink cartridge that causes ink leakage leading to unacceptable product quality.
5. Ships are damaged by ice during winter.

These problems have been also chosen for their different characteristics in order to evaluate the capability of BOB-UP® to drive users towards the right reformulation of different kinds of problem (e.g. elimination of negative actions, improvement of systems with problems of underperformance, and increasing the control of excessive or uncontrolled actions).

*5.3 Tests execution*

Tests have been executed in the computerised laboratories of the University and organised as follows:

- The first and second group of students had to reformulate and solve the 5 test cases using only the learned problem structuring and solving techniques.
- The second group had to perform the same test cases using BOB-UP®.
- The students of third group had to solve always above-mentioned 5 industrial cases in two steps. First the students had to solve the problem by their own without the aid of BOB-UP® tool. In this case, a classical cause-effect chain and a concise description in natural language of the problem to be solved were required. Then, they had to face the same problems using BOB-UP® and the needed output were the problem reformulation, the final sketch, the Ill-Balls and Fight diagrams. Both in the first and second part, solutions generation were recommended but not mandatory.

During the text execution, Internet connection and all type of knowledge retrieval were allowed.

## 6. Results and discussion

*6.1 Evaluation criteria*

The variety of students' competences and test cases permitted to evaluate:

- Capability of BOB-UP® to lead the students to a correct understanding of the problem and performing a right reformulation of the initial problem;
- Capability of BOB-UP® to lead the students to identify solutions for the proposed problems;
- The impact of students' knowledge on problem structuring and solving techniques when using BOB-UP®.

To evaluate mentioned aspects following criteria have been considered:

1. Right identification of the element which suffers from the undesired effect;
2. Right identification of the operative zone of the element which suffers from the undesired effect;
3. Right identification of the operative time of the harmful effect and its physical interpretation;
4. Right identification of the cause element and its operative zone.

The students were also asked to fill a questionnaire to comprehend their perception of the tools potential and which steps and instruments had been considered more useful and/or difficult to understand and use.

The comparison of results reached by the first and second group permitted us to evaluate how much BOB-UP® can improve student's skill in problem structuring and solving. Results of tests with the third group have been elaborated and analyzed to identify pros and cons of the CAI tool. Finally, the comparison of results from Group 2 and 3 permitted to understand to which extend BOB-UP® can help engineers to identify and reformulate the right problem without having specific skills on related methodologies.

In the following we summarized analysis of mentioned results.

*6.2 Group 1 vs. Group 2*

Students of the first and second group carried out a right and exhaustive reformulation of the initial problems in most cases. This demonstrates that a good knowledge of problem structuring and solving methodologies is sufficient to reach a satisfactory problem reformulation, also without CAI tools. However, some differences can be highlighted. Formalizing with BOBUP® the problems already faced up in the first session, group 2 proposed new solutions, and a more accurate problem definition. In particular, it has been observed that the use of the Ill-Balls diagram allowed identifying the right level of detail for problem analysis, increasing the problem space and offering new directions.

New solutions are not quantitative relevant for a so narrow statistic but qualitative interesting due to their location mainly on the element causing the harmful effect and applied on a more restricted and localized area (referable to the operative zone of the harmful element). This means that BOB-UP® forces the students to a deeper and more efficient space-time collocation of the harmful effect root cause. Moreover, Ill-Balls diagram can be suggested also as a useful and independent practice for problem solving analysis.

*6.3 Group 3 Results*

The results of the third group show how BOB-UP® is able to enhance the students' capability of understanding and reformulating problems. Results demonstrated that it improves students' skill both in problem structuring and solutions identification.

As said, students were first asked to find solutions without any aid and, then using BOB-UP®.

Two main considerations can be reported:

- Problem physics. Without any support, about 55% of students understood the real physics of the problem and how the harmful effects act, but the percentage greatly increased till 78% when BOB-UP® is used. In fact, the step-by-step guided procedure and available tools (e.g. Fight diagram) oblige the user to analyze in an unconventional way the problem from a physical point of view.
- Number of solutions. During tests, solutions generation was recommended but not mandatory; nevertheless, solutions have been identified during both steps. In particular, 54% of students proposed at least one solution during the 1st step. Using BOB-UP® the percentage increased to 70%, but the meaningful result was the number of new and valid solutions that increased by 43%. Also the quality of solutions was enhanced: they were more localized and limited to the identified operative zones of the harmful element, and sometimes also in time. This relies on the fact that BOB-UP® provides specific tools to identify as the cause of the harmful effect a specific element (not a parameter) well defined in space and in time.

Evaluating results against the aforementioned criteria, we can summarise as follows:

- Criteria 1: Most of students (91%) have identified the right element affected by the harmful effect.
- Criteria 2: 81% of students (all of them satisfying criteria 1) identified the right level of detail for the operative zone of the harmful effect.
- Criteria 3: During the phase of problem formulation without BOBUP®, the students didn't fix a specific starting moment to describe the harmful effect, except few cases (10%). Then, the procedure forced to fix this moment but with a low success rate (33%).
  Meaningful mistakes can be traced back to two situations:
  - 39% of students performed a correct harmful effect investigation/analysis but they described the operative time as a process instead of using the Fight diagram to identify a precise instant;
  - 11% of students identified the operative time inside a too generic operative zone, i.e. with low level of detail.

  However, when the Fight diagram was well applied, a better (and often inedited) description of the physics of the problem appears. The use of Fight diagram to perform a better harmful effect investigation and time collocation has been confirmed.
- Criteria 4: The cause element specified into its operative zone has been identified by 51% of students. This because, the cause element identification is the last part of the procedure and it suffers from the mistakes done previously. However, after a carefully analysis, two significant problems have been detected:
  - Difficulty in identifying an element as a cause. About 10% of students identified the cause of the harmful effect as a parameter or an action (temperature, pressure, the increasing of temperature, etc.) instead of an element.
  - Difficulty in identifying the precise part of the harmful element, which really causes the harmful effect. About 27% of students had this problem. This may be traced back to an absence of a dedicate tool such as the Ill-Balls diagram, entirely dedicated to increase the attention to this part of the problem. Being at the end of the procedure, user tends to perform this task more quickly and with less accuracy.

Figure 6 shows the success percentage rates for each evaluation criteria.

Finally, the students filled a questionnaire about BOB-UP® usefulness and efficacy. It has been divided in two main parts and contains 7 questions, some of which open. The 1st part deals with students' personal knowledge on test cases topics and problem solving techniques, while the 2nd part is focused on the evaluation of BOB-UP® procedure. In particular, the students had to evaluate provided tools considering level of difficulty and capacity to support them along the procedure steps and sub-steps.

Results of students' subjective evaluation confirmed that the CAI tool supports effectively the problem reformulation. Fig. 7 shows that 93% of students considers useful or very useful BOB-UP® to understand, reformulate and also solve problems, only few (3.5%) considered it not adequate.

Figure 8 shows when BOB-UP® has been considered more useful. Remarkable is how BOB-UP® procedure mainly helped students in identifying the operative zone of the cause and damaged elements.

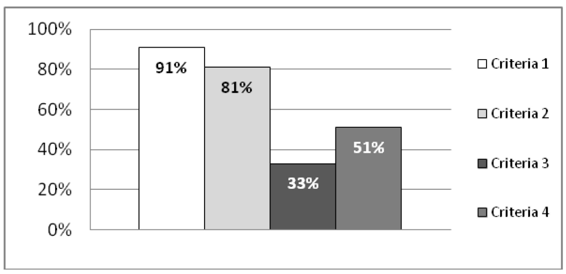



**Fig. 6.** Success percentage rates for each evaluation criteria.

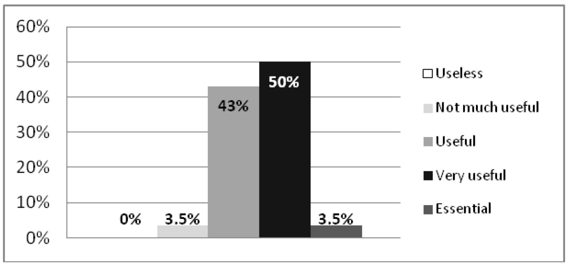



**Fig. 7.** BOB-UP® usefulness in problem formulation.

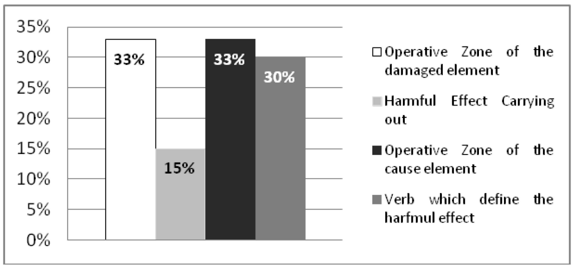



**Fig. 8.** Where BOB-Up is perceived more useful.

One third of the participants recognized the procedure useful to better define the functional description of the harmful effect.

In the last part of the questionnaire, the students judged the level of difficulty and the usefulness of the steps.

Figure 9 shows the most difficult and useful steps.

Students considered the Fight diagram the most difficult step, because this fighting physical modelling is not conventional. In any case, it is obvious that the critical part of every cause effect analysis is to understand all the hidden physical dynamics.

Only 13% of students found a hard task to follow a so strict dialogue based procedure, even if, they recognised its usefulness. For 9% of students the most difficult step is the identification of the element, which causes the harm. This can be due to the general trend to identify the cause as a parameter of physical phenomena instead of linking it to a proper element.

The most useful step has been judged the Ill-Balls diagram, because it helps to fix the level of detail in the harmful effect analysis. Fight diagram and harmful effect definition are the second and third useful sub-steps. Although, they are also the two most difficult sub-steps, students evaluated their usefulness to perform a correct physical investigation and to define the harmful effect in the correct way.

### *6.4 Group 2 vs. Group 3*

This comparison has been performed to evaluate the influence of specific skills in structuring and problem solving.

The students of the second group were able to perform a better space-time collocation of the harmful effects than students of the third group. The improvements mainly concern the accuracy and precision with which the operative zone and the operative time of the harmful effect have been identified. The reason is a more rigorous and efficient use of BOB-UP® tools thanks to a good knowledge in using problem solving and structuring techniques, and a greater awareness of the goal of each step.

Finally, even if there are no significant differences for the number of proposed solutions, the quality of the solutions proposed by the second group is better due to a more accurate reformulation.

## 7. Conclusions

This paper presented BOB-UP® tool as well as its experimentation within engineering courses. BOB-UP®, based on the homonymous methodology and currently patent pending, is a CAI tool specifically conceived to enhance the capability of problem structuring, i.e. to identify the right problem and to avoid wrong interpretations that can lead the designer to find erroneous solutions. The methodology integrates a set of concepts, such as operative zone, negative and natural systems within a traditional cause-effect framework to guide the user to define a more rigid formulation of the problem. BOB-UP® has been tested with engineering students characterised by different competences on

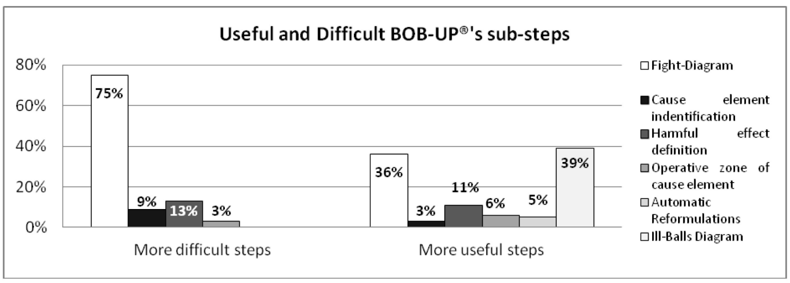



**Fig. 9.** Difficult and useful steps.

problem structuring and solving and technical backgrounds (mechanical vs. management engineering students). To this end, five test cases related to different industrial applications have been considered. This helped us to understand the potential of the tool and underlying methodology as well as its level of usability. Results, as described in the previous chapter, have been considered satisfactory and interesting especially for people without a deep knowledge on problem structuring and solving even if better results can be reached with skilled students. Students' subjective evaluation confirmed that the CAI tool supports effectively the problem reformulation and permitted us to identify most useful and or/ difficult steps and tools.

The Ill-Balls diagram has been considered one of the most useful since it helps to identify the level of detail in the harmful effect analysis. The Fight diagram has been identified as one of the most difficult to use even if its usefulness to perform a correct physical investigation and define the harmful effect has been proved. In general, the step-by-step application of the procedure along with the use of graphical tools and sketches have been considered positively; however, improvements have been envisaged to make BOB-UP® more user-friendly and to shorten the procedure.

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