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# Engineering designer curricula and creativity development

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## Abstract

*Product eco-sustainability and cheapness are two of the main strategies adopted in the contemporary market to exit from the current economical crisis, as testified by the adoption of several ideas of the green-economy. The design of product according to these new requisites will entail new challenges for engineers: their creativity will gain more and more importance to find out new design "starting points" and to conceive new industrial products. These considerations are the basis of the proposed curricula modifications.*

*Since we believe that at least an embryo of creativity could be found in everyone, the main goal of our curricula proposal is to start the growth of this embryo, showing to the students how to study also old problems from different points of view.*

*The described proposal, conceived to achieve this goal, comprises the upgrading of the curricula, by including some topics concerning technical history and nature observation as sources of innovative technical solutions.*

## 1 Introduction

In the contemporary international economic scenario, political, economical and scientific communities agree that innovation and research are critical for our society future development. In this perspective, engineers will be called upon to develop innovative solutions to meet more stringent economic and eco-sustainability requirements. New cultural profile may therefore be required in the future for engineers. This tendency is evident also today: engineers capable to innovate are greatly appreciated in the industrial and economical world.

Nevertheless, engineering curricula in most technical universities do not include courses centred on the development of creativity. In the past, when the needing of innovation was not so compulsory as nowadays, the on-field learning was the best instrument to learn how to design. In the modern economical and technological context, also "young" engineers are called upon to give valid and constant contributes to the innovation process. Young engineers' contribution may even be the more innovative: they are not yet accustomed to the "conventional" design solutions.

Since engineers play a key role in the technological and economical development of our society, their education will be discussed in the next sections; more in detail, the mechanical engineer education will be considered, since the authors have a direct contact with this field of engineering education.

Firstly, it is worth defining exactly what we mean speaking of design in the mechanical engineering field: design is the individuation of all the information that will be necessary and useful to conceive, produce, assembly and use any product.

Secondly, we define "creativity" as the "ability to propose innovative principles and/or constructive solutions to perform a given function". It seems evident that this characteristic is mainly needed in the first steps of the design process.

Thirdly, it is necessary to define the more important aspects of creativity for an engineer. A direct answer to this question is quite difficult, while, in our opinion, it is quite easy to describe a creative engineer: he/she realizes things that no one has done before. In the engineering field, usually, this does not necessarily imply the industrial exploitation of recently discovered physical phenomena; "things that no one has done before" are more commonly achieved using well know technologies in new ways and/or fields. In other words, in the present paper, every solutions not yet existing, or every know solutions applied in a new context or in a new field will be called an innovative solution.

The discovery of new knowledge, the invention of new technologies and the analysis of situations in new ways are therefore three particularly important aspects of this "instance" of creativity.

Even if an important role is obviously played by the natural skills of each student, we believe that at least an embryo of creativity can be found in everyone. The main goal of our curricula proposal is then to start the growth of this embryo, showing to the students how to study also old problems from other points of view. This kind of approach should allow to individuate the critical points that leaded to the adopted solution and to develop alternative and more advantageous solutions.

These solutions can obviously have different level of complexity and reach various degrees of innovations: new solutions can be found, for example, transferring constructive solutions developed in other technological fields, as well as exploiting newly discovered physical phenomena.

In our opinion, these considerations are among the main reasons why, in the past, the growth of "creativity" was based on the on-field experience: an experienced engineer has a wider personal library from where he/she can draw inspiration to cope with conceptual and practical aspects of the complex task of engineering design. These and other considerations [1] suggested us the idea to link analysis, conservation and organization of historical heritage to the development of existing or new products.

The education of an engineer, who will actively operate in the design field, has then to stimulate the growth of his/her creativity, so that he/she can be able to individuate new principles and constructive solutions for industrial products as soon as he/she begins to work.

The considered source of inspiration are the historical heritage, the state of the art (for the know principles and constructive solutions), the heuristic methods (like TRIZ) and nature observation. These sources can obviously help senior engineers too, allowing them to choose solutions among wider libraries of solutions.

The choice among all the found principles and constructive solutions can be performed evaluating how these behave in each phase of the product life cycle, using methods like LCA and DfX.

## 2 Goals

The aim of the present paper is to define a set of courses to be included in the engineering designer curricula, with the precise scope of developing student's creativity.

The main goal of these courses is then to start the growth of young engineers' creativity embryo. This purpose can be achieved teaching them methods and means to accomplish the first steps of the design process, corresponding to the individuation of the principles and constructive solutions to perform a given function.

## 3 Methods and tools

One of the approaches we use to help students in the initial phases of the design process is summarized by the logical schema depicted in Figure 1. This approach has been derived on the basis of the TRIZ method [2] [3]. In fact, roughly speaking, one of the TRIZ "suggestions" is to face a problem under a more general perspective. In this way, it is easier to find out unconventional solutions, or to understand if it is possible to outflank the problem. This "general" solution shall then be particularized in the specific field.

On the contrary, usually, a problem is solved directly, by means of the personal experience of the designer (lower path in Figure 1): this way usually leads to design without innovation (because of the so called psychological inertia).

The proposed approach (upper path in Figure 1) consists in redefining the specific problem through an abstraction process, so that the problem can be faced under a more general perspective, enlarging the field of the possible solutions. When the "general" solution has been determined, it can be instanced in the specific situation through a concretization process.

From a didactic point of view, this way of thinking forces students to search for solutions among every field of their technical and scientific knowledge. This approach is also a strategy to overcome the first of the above cited obstacles: students' knowledge is quite small, since they usually have no practical experience at all. This lack of information can be somehow over helmed by means of software tools by means of which they can search for constructive solutions (historical heritage and natural phenomena archives are two examples of possible sources of solutions).

Anyhow, in order to avoid that students are induced to simply copy previously develop solutions, TRIZ and other heuristic methods have been included among the main topics of the "Design Methods" course, taught by one of the authors.

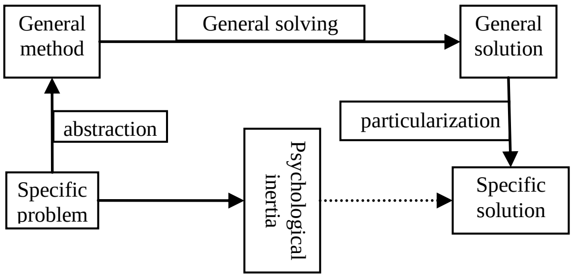

***Fig. 1 General schema derived from TRIZ and utilized to upgrade the student's creativity.***

The needing of this kind of archives and authors' interest in methodical design and in technical history itself are the two main reasons that induced the authors to realize archives of constructive solutions and to activate the course "History of Mechanics", held by the same author.

Student's works developed during this course are also used to build a set of archives of a wide variety of industrial products or of their parts.

Another rich source of innovative solutions is Nature. The usage of this source of inspiration, obviously, requires a deep knowledge about natural phenomena, but this field is actually absent from most of the engineering education curricula. It can be then useful to introduce a course to introduce the students, at least, to the basic biomimetic methods and techniques, showing them some practical applications.

Student's lack of experience may also be a source of some difficulties in evaluating how each solution behaves during its life-cycle and, therefore, in choosing the "best" one among all the others. In order to overcome these difficulties, the course "Design Methods" program includes also the DfX principles and methods.

When students choose to attend both the abovementioned courses (and this happens quite often), they can develop an integrated work about the same industrial product, completing the first steps of the design process.

## 4 Practical examples

Two examples extracted from the didactic experience of the Authors are described hereafter.

### 4.1 Historical

Starting from an archive of drawings of car suspensions [4], several groups of students have been invited to propose innovative solutions. Starting from the German patent (1940) (Figure 2) of a device for the adjustment of the high of a car body by using only mechanical systems, first, students determined the general principle (i.e. the height variation of the fixed point of the spring with respect to the vehicle body), and then applied this principle in a suspension with torsion bars [5] (Figure 3).

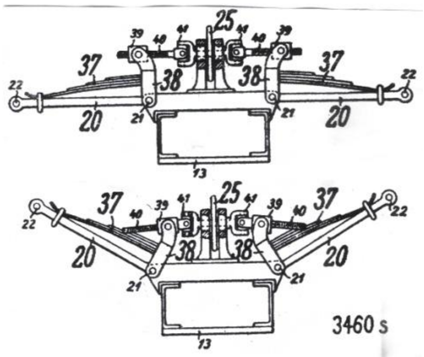

***Fig. 2 German patent (1940) of a car suspension with possibility to adjust the high by using only mechanical devices***

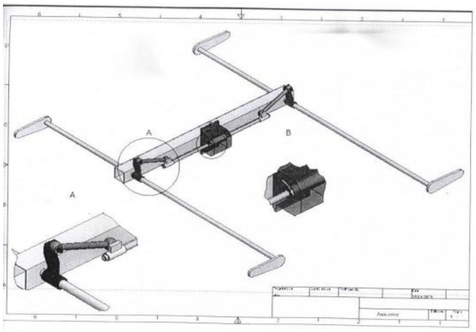

***Fig. 3 The principle of the figure a generalized and applied to a suspension with torsion bars***

On the basis of this and many other similar experiences, it is author's opinion that systematic archives of constructive solutions (catalogued on a functional basis, with some analogies with CREAX function data-base [6]) are a significant opportunity for students and engineers.

The authors are collecting students' Excel sheets where students collected historical constructive solutions.

Figure 4 shows a sample Excel file. It is worth noting that in this Excel file students are asked to store not only the main technical data of each solution (like tubes and wheel size, derailleur data for the bicycle), but also to describe how this structure works, in a so called Behavior field. This has two beneficial effects. Firstly, from a didactic point of view, students are not called to a simple data-entry activity, but they are also asked to understand the physical phenomena on which the system is based and the corresponding fundamental laws. Secondly, under an engineering perspective, this field is precious for a designer that wants to exploit this solution in another technological field, or to improve the product itself.

Several complete examples of historical evolution of engineering applications are freely available in the "*Mediateca per la Storia dell'Ingegneria*" of the web-site of the *Conference of the Deans of the Italian Engineering Faculties* [7].

### *4.2 Biomimetic*

As an example, a group of students, starting from the motion of fishes (Figure 5), proposed a device for the propulsion of ships (Figure 6) [6].

Authors' research activity is oriented to the development of a software tool composed by a web interface and two data-bases. The first data-base will contain the historical data, while the natural solutions will be stored in the other one. Both will be organized on a functional basis, so that, through the web interface, the users will be able to retrieve solutions from both archives at the same time.

Figure 7 shows an example of the search result of a test data-base of biological solutions stored on a functional basis. Also in the biological solutions data-base, besides the fields designed to store the taxonomy, biological data and structure, we have added a field to store an engineering-oriented explanation of how the function is exploited by the considered species.

## *5 Courses proposal*

Starting from these considerations, the Authors have drawn the following considerations and proposal about curricula for engineering students.

### *5.1 Terminal behaviour*

In the communication techniques the "terminal behavior" is defined as the formalization of the competencies to be reached by the users of the communication (i.e., the students) after the communication itself.

We will assume that the terminal behavior of an engineering student educated to be creative can be briefly summarized in the following aspects:

- have a quite clear idea of creativity definition;
- be aware of its role in engineering design;
- know the more important tools and methods to develop creative solutions;
- be able to use these tools and methods.

### *5.2 Dublin Descriptor and RULEG method*

How to reach these competencies can be studied by means of the Dublin's Descriptors, a tool today widely used in engineering education [8]. These descriptors state that the student has to reach the following goals during his/her education:

1) knowledge and understanding;
2) applying knowledge and understanding;
3) making judgements
4) communication skills;
5) learning skills.

A comparison between the Dublin's Descriptors (DD) and the "RULEG" method [9], used by authors in the engineering education, shows that this teaching method is suitable to help students to reach these skills.

The RULEG method is mainly based on the "communication unit" (i.e. the part of communication devoted to the transmission of a specific concept), that can be decomposed in three main parts: informative (rule: RUL), critical (complete example: EG) and practical (incomplete example: EG*).

In engineering education, the deductive method (RULEG) is often utilized, since the definition (RUL) is always followed by some examples (EG).

The general configuration of the "communication unit", then, is expressed as follows:

RUL + EG + EG*

Comparing the DD with the RULEG method, the following considerations can be drawn:

6) in the Dublin's Descriptors, the knowledge (informative, RUL) and the comprehension (critical, EG) are considered together;
7) "making judgements" can be considered a part of the comprehension ability;
8) the "Applying knowledge and understanding" ability of the DD is somehow equivalent to the applicative part (EG*) of the RULEG method;

Communication and learning skills, together with knowledge, comprehension and application aspects, can be considered topics to be directly taught, in specific courses or, at least, in on purpose parts of other courses.

On the basis of these observations the correspondences listed in Table 1 have been derived.

### 5.3 Proposal

In the Bachelor Degree, the creativity-related topics can be included in the syllabus of the courses about Machine Drawing and Computer Aided Engineering Design. However, in the Master Degree, besides the course "Design Methods", we propose the institutionalization of the course "History of Mechanics" and the introduction of a new course focused on "Observation of Nature".

Table 6 shows the aspects that should be considered introducing creativity in the Bachelor Degree courses, while table 7 shows these aspects for the Master Degree.

## 6 Conclusions

Authors' experience confirms that the critical observation of historical heritage and natural phenomena are tools that can be successfully used to upgrade the creativity of students of engineering design courses.

By means of the Dublin Descriptors and RULEG Method, some proposals about the engineering students' curricula have been introduced.

| Type of cycle | Year of invention | Place of invention | Generic picture | Dimensions | Structure |
|---|---|---|---|---|---|
| city bike | 1868 | France |  | seat tube: 45-65 cm<br>wheels: 12"-20" children, 24"-28" normal<br>top tube: 50-60 cm | frame usually made of aluminum alloy, simple, rugged, equipped with mudguards, chain guard and rack, often single speed. Triangular tapered seat. Possibility of mounting basket or child seat in front of the handlebars. Often the presence of lights powered by dynamo |
| racing bicycle | 1885 | Italy |  | seat tube: 45-60 cm<br>wheels: 26"-28"<br>top tube: 50-60 cm<br>wheelbase: 98-102 cm | Superlight(in composite materials or aluminum alloys), has a curved handle and not very wide with the handles parallel to the front wheel to allow the speed control. The seat has an aerodynamic shape, long and narrow, to avoid the actress on the legs. no fixture, is used to cycling on the road, track or sports |
| mountain bike | 1976 | California(USA) |  | seat tube: 38-55 cm<br>wheels: 22"<br>top tube: 55-65 cm<br>wheelbase: 105-120 cm | particularly strong, right handlebar that allows a better control over the direction of the bike in difficult terrain, with wide range of exchange and suitable for cross country thanks to the presence of suspensions |
| recumbent bicycle | 1933 | France |  | seat angle: 25°-50°<br>wheels: 20"-28"<br>wheelbase: 110-130 cm<br>seat height: 25-65 cm<br>length: 160-230 cm<br>height: 80-110 cm<br>width: 50-100 cm | the back is supported by an inclined seat, the legs are extended forward on the pedals, which are roughly the same height of the seat. The handle can be above as below the seat. The wheels are generally smaller and more spread out than a conventional bicycle |
| folding bicycle | 1878 | Great Britain |  | seat height: 60-100 cm<br>wheels: 16"-20"<br>folded: 60x40x60 variable<br>wheelbase: 100 cm | bike with small wheels that has built such devices hinges, plugs and / or devices that enable rapid tightening of fold or disassemble the bike quickly and easily into a manageable size so small that it can be transported as checked in another half transport |

**Fig. 4 Example of historical evolution (bicycles).**

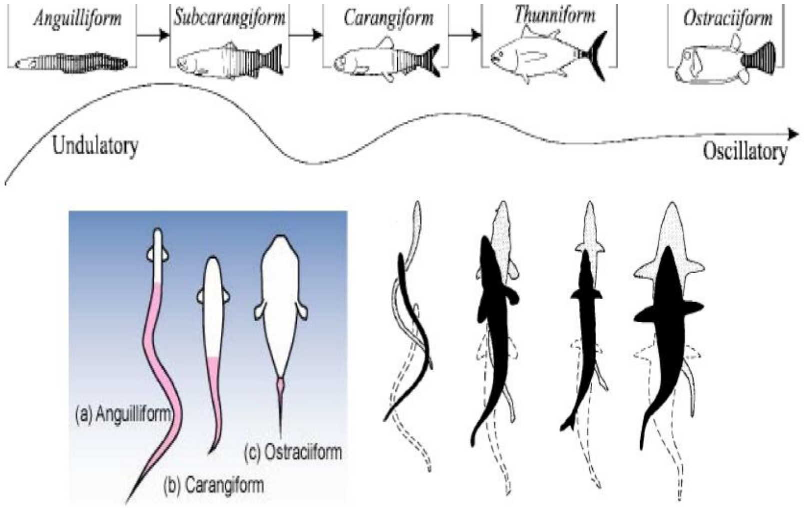

**Fig. 5 Fish swimming styles.**

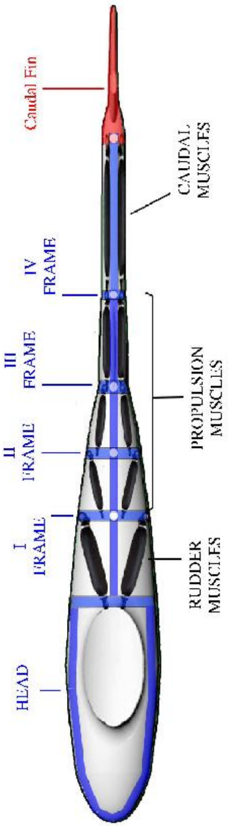

*Fig. 6 Device for the propulsion of fishes derived from the studies of motion of fishes.*

| Dublin's Descriptors | Parts of terminal behaviour (RULEG) |
|---|---|
| Knowledge ability | Informative (RUL) |
| Understanding ability | Informative (RUL) |
| Making judgements | Critical (EG) |
| Knowledge and understanding ability applied | Practical (EG*) |

*Tab. 1 DD and RULEG comparison.*

| Dublin indicators | Parts of terminal behaviour | Example of contents |
|---|---|---|
| Knowledge and understanding ability | Knowledge (informative) | Definition of creativity |
| | Understanding (critical) | Why creativity in design engineering is important and the relative role |
| Knowledge and understanding ability applied | Application (practical) | Heuristic methods to develop new principles and constructive solutions |
| Knowledge and understanding ability | Knowledge (informative) | Definition of creativity |

*Tab. 2*

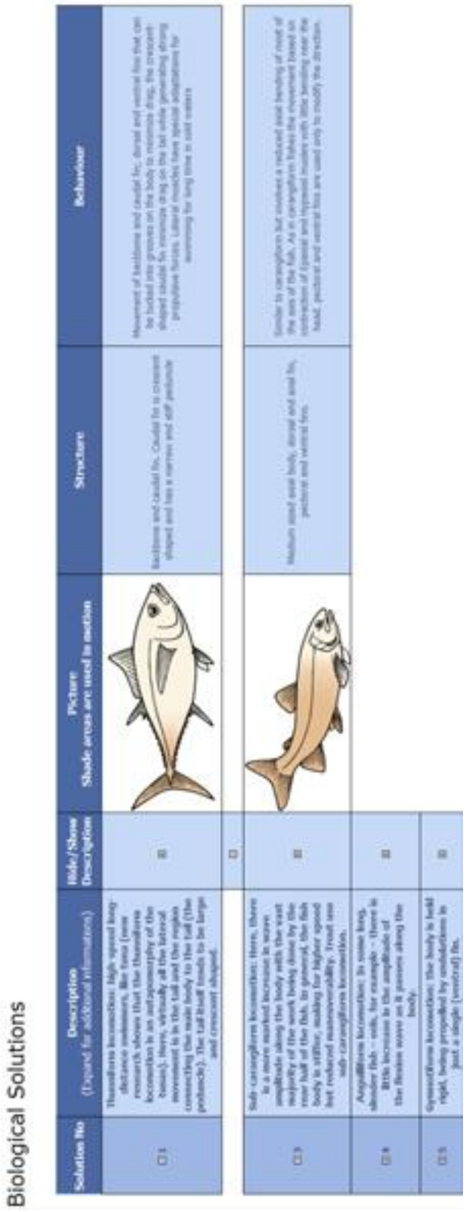

*Fig. 7 Example of biological solutions (fish locomotion).*

| **Dublin indicators** | **Parts of terminal behaviour** | **Example of contents** |
|---|---|---|
| Dublin indicators Knowledge and comprehension ability | Knowledge (informative) | Some methods to develop creativity (historical heritage, observation of nature, TRIZ) |
| | Comprehension (critical) | Differences and peculiarities of the above mentioned methods |
| Knowledge and comprehension ability applied | Application (practical) | Apply the abovementioned methods to develop innovative solutions |

***Tab. 3***

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