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BIO-INSPIRED IDEATION: LESSONS FROM TEACHING DESIGN TO ENGINEERING STUDENTS

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ABSTRACT

Biologically inspired design uses inspiration of natural systems to develop solutions for design and engineering problems. We experienced teaching bioinspired method to engineers in the context of problem solving course in Fall of 2012. The aim of this study was to investigate and understand the perception of bioinspired design by engineering students and to provide insight into problem driven and solution driven approaches as a type of design ideation pedagogic method. This paper provides the detail of analysis of ideas and summarizes our main observations: 1) Difficulties to follow problem driven approach rather than solution driven; 2) Distinct preference of inspired ideas for product, process, service and system domains.

Keywords: ideation, innovation, biomimetics, bio inspiration

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1 INTRODUCTION

Biologically inspired or Biomimicry is basically the idea of using natural world elements to inspire engineering designs. There is an increasing interest in many engineering disciplines and considered as an emerging field in design, mainly because learning from how nature makes things happening is generally accepted as a sustainable design approach (Anastas and Warner 2000; Benyus 1997; Wann 1990).

In the very initial phases of the design process, an intelligent act happens in the designers' mind, seeking for a starting point in order to build new principles. This act, described in many terms such as creativity or ideation, is a process of transforming, combining and adapting elements for developing new ideas for new products. In this respect everything can be a source of inspiration to a designer.

Biologically-inspired solutions are often novel and innovative, but generally, the inspiration happens by chance or through dedicated study (Nagel 2010).

Designers or engineers attempting to use biological systems to inspire engineering design solutions face the challenge of drawing useful analogies between the two domains of biology and design. The research effort in this field is to create knowledge, methods, and tools to facilitate design activities. One major difficulty in this context is the lack of formalization of a methodology. So far, despite of a few attempts for proposing a methodological framework, the bio-inspired approach is not commonly known as a design method, likewise the engineering design methods, and remained within informal approaches in engineering design.

Nagel (2010) put the bio-inspired design literature into five categories, summarized in table 1. This classification helps to understand the focus of research in bio-inspired design, and the technical background for developing appropriate support tools. Other classifications are also suggested in the literature, for example in (Trotta 2011).

Table 1. Classification of bio-inspired deign methods and approaches, adapted from (Nagel 2010)

Category		Description	Key publications
1	**Inspiration Facilitators**	Analogy between biological and engineering principles, components and systems, using keyword searching	(Hacco and Shu 2002) (Chiu and Shu 2007) (Nachtigall 2002)
2	**Representation Methods**	database of natural and complex artificial mechanical systems, engineering problems that can be solved by biology, Functional Basis to biological systems to discover analogous engineered systems	(Chakrabarti et al. 2005) (Vincent et al. 2006)
3	**Information Transfer Methods**	methods of aesthetic design, material design, determination of biologically meaningful terms and transferring biological principles	(Wen et al. 2008) (Cheong 2008)
4	**Concept Generation Techniques**	diagrammatic and textual descriptions of biological organisms, strategies or phenomena	(Vattam 2009) (Wilson 2009)
5	**Holistic Design Approaches**	Approach to design following a step by step process, considering the biological inspiration as a solution search / identification phase.	Biomimicry Institute (Helms et al. 2009)

While methods in category 1 to 4 in Table 1 concentrate on a systematic way for seek and find related biological solution to the pre-defined functional problems, holistic design approaches aim to a process of problem definition and solution refinement. Problem driven and solution driven called directed methods from Center for Biologically Inspired Design are the most known. Directed methods are simple and easy to understand and seem to the logical deduction of a design progression. Helms et al.

(2009) provide a descriptive account of directed method and proposed a process for design, and point out the advantages of realism and accuracy of predictions of design behaviors.
Despite the lack of an engineering design type method for bio-inspired design, different approaches of bio-inspired design are commonly acknowledged within the design community and are recommended by several design textbooks. An addition, those methods are successfully employed for several PhD thesis, and shown to mainly result in innovation (Collins 2004; Forbes 2005). Bio-inspired design is now thought in a few design courses. Hence, the pros and cons of using bio-inspired design either as an ideation method, or as an educational method are not clear. Glier reported in (Glier et al. 2012) that bio-inspired design is advantageous for novice designers, however there was no significant difference in the performance of novice designers using no formal ideation method and the directed method. Helms pointed out the common errors of the bio-inspired design process, and noted the differences between problem driven and solution driven design projects (Helms et al. 2009).
The objective of study behind this paper was to investigate the advantages of bio inspired design as an ideation method to engineering students. Engineering students population despite design students particularly in French general engineering school receive a highly industrial oriented training, and rather familiar with algorithmic problem solving of tangible and practical engineering problems.
Nonetheless, we chose a group of last year students of general engineering who were under the Design and Innovation of Industrial Systems minor for the experiment. Because of their minor and because of the choice of Problem solving module, we made the hypothesis that they are within the most interested students in innovative design. The students have selected the Bio-inspired design course over four other parallel courses of problem solving module, and have expressed their interest in innovation inspired by nature in written half page essay.
We chose to alight with the directed method in teaching and in experiment because of the simplicity and the process view. The following section reformulates the understanding of directed methods of bio-inspired design and describes the challenges of using this approach as an engineering design method. The experiment was basically asking the students to generate new ideas using either problem driven or solution driven approach. This is presented in detail in section three as the context of the study. Section four shows the analysis of undertaken projects and argues the obtain results. Finally, we discuss the conclusions of this investigation and avenues for further research.

2 PROBLEM DRIVEN AND SOLUTION DRIVEN APPROACHES

In directed method, containing problem driven and solution driven approaches the designer learns to consider how nature would solve the problem. In other words, as Benyus formulates, when looking for a solution, ask nature first (Benyus 2007). Helms describes the pattern of bio-inspired design as the progression of six steps, shown in Figure 1. These steps are considered to be non-linear and dynamic in the sense that output from later stages frequently influences previous stages, providing iterative feedback and refinement loops (Helms et al. 2009). The final objective of this process is to help the designers extract the biological solution; translate it from biology to mechanical engineering by introducing new constraints.

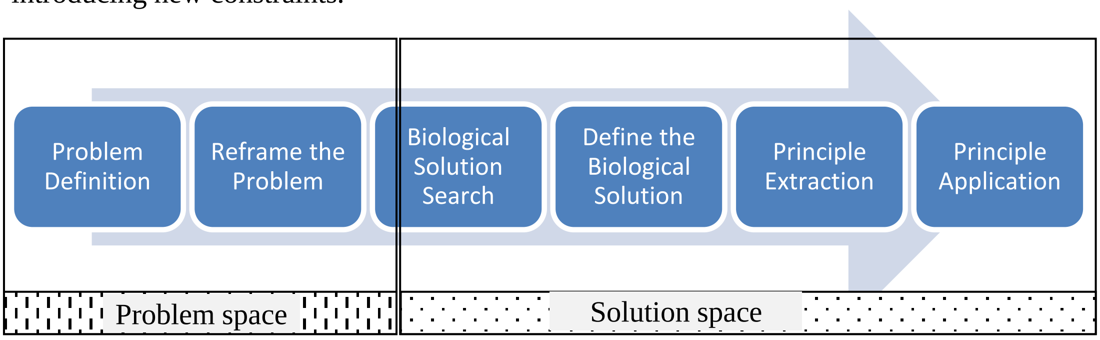


Figure 1. Problem driven approach extracted from (Helms et al. 2009)

In the same study, Helms explained another process of design, beginning with a biological solution, extraction of what they called “a deep principle”, and then finding problems to which the principle could be applied in general. The step to be followed in this approach is shown in Figure 2. It is pointed out that in practice this process in not necessarily ordered linearly.

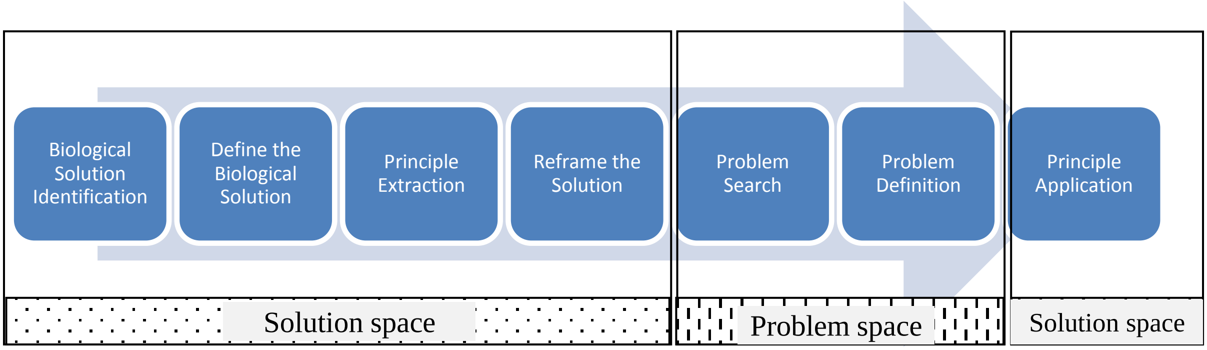


Figure 2. Solution driven approach extracted from (Helms et al. 2009)

These two approaches of directed method simply direct the designer to look and understand how nature accomplishes a task, and find a way to do similarly for a design problem. However, what happens more often than not is the fact that a task done in biological way is to fulfill a complex objective, usually known to the designer. In other words, it is almost impossible to find an isolated mechanism for a unique function in nature. As a result, the way nature acts, can be considered as a solution (observable and measurable task or mechanism) for a partially known objective. The design can *inspire* from the biological happenings to solve a known and defined design problem. In practice, the design team suffers from lack of biological knowledge, so it will often recruit a biologist to expand the team's knowledge base and increase the likelihood of finding a bio-inspired design solution, which leads the team to innovative design solutions (Bar Cohen 2003; Glier et al. 2012).
The step by step process description of design shown to be of many advantages, particularly in design education. Besides, one of the most noteworthy ideas to emerge in recent years is that creative design concepts can be viewed as being developed through an iterative process, whereby the design problem and potential solutions co-evolve over time, with the designer exploring two conceptual spaces, a problem space and a solution space, with each space informing the other (Wiltschnig et al. 2013). According to this iterative, both problem space and solution space need to receive consideration in the context of requirements. This study aimed at using directed methods, but emphasizing the problem space and solution space in the ideation phase. For this purpose, a certain number of questions was prepared to accentuate each space within the design task. The following section presents the experiment and the design assignments.

3 THE CONTEXT OF THE STUDY

Bio-inspired design is a project-based last year class open to undergraduate general engineering students enrolled in Design and Innovation of Industrial Systems minor, problem solving module. At the time of the experiment, students learned about innovative design principles, but not particular design method. For the course, students followed several case based lectures on bio-inspired design, and an introduction to the directed approach (problem driven and solution driven). As the first assignment, each student was requested to submit between 4 and 6 ideas, using both approaches preferably equally. The idea submission was through an online form, which made them follow four steps for both problem driven and solution driven approaches. Table 2 shows the list of questions for the idea submission. They were also asked to mention whether the biologically inspired idea comes from their general knowledge, or a resource (such as www.asknature.org) has been consulted. Twenty six students participated in this experiment in a three day workshop. The experiment took place in class room where everybody worked individually and used a computer for online research and submitting results through a predefined online assignment page (question is Table 2).

4 RESULTS

A total number of 118 ideas has been received by the end of the workshop. In the next step, all ideas are evaluated using simple criteria of maturity in problem and solution spaces, shown in Table 3. A note of 3, 2 or 1 is attributed respectively for good, acceptable and weak statements for problem space and solution space of each idea (Table 3). This rating is performed by four academic evaluators; two of them were not familiar with the course context. Finally the ideas are labeled with the application domain within Product, Service, Process, and System. The notion of "good idea" is given to ideas with the total note greater than 5. Accordingly, “acceptable idea” is an idea with the total score between 3 and 5, and a “weak idea” is the one with total score less than 3. The reason for this labeling is to provide a rather representative measure than the total idea number. Nonetheless, the total number of ideas in each application domain is simply accessible from adding the number of good, acceptable and weak ideas.

Table 2. Questions of bio-inspired idea submission assignment

Problem driven approach	Solution driven approach
1. What is the industrial problem?	1. What is the observed solution in the nature?
2. What are the requirements to solve this problem?	2. What are the main principles of this natural solution?
3. What is the principle requirement?	3. What is the principle mechanism of this solution?
4. What natural or biological solutions could help to solve this problem?	4. What industrial problems could benefit from this mechanism?

Table 3. Evaluation questions for problem and solution spaces

	Problem driven approach	Solution driven approach
Problem space	Description of the industrial problem and requirements	Description of the problem situation in nature
Solution space	Explanation of how a biologically inspired idea could solve the problem	Explanation of how the inspiration could solve an industrial problem

At first glance almost two third of the submitted ideas fell into solution driven approach. In 118 ideas, product (73 ideas) and system (30 ideas) are the most favorite application domain categories for the students. Figure 3 shows the distribution of the ideas in four categories in both approaches.

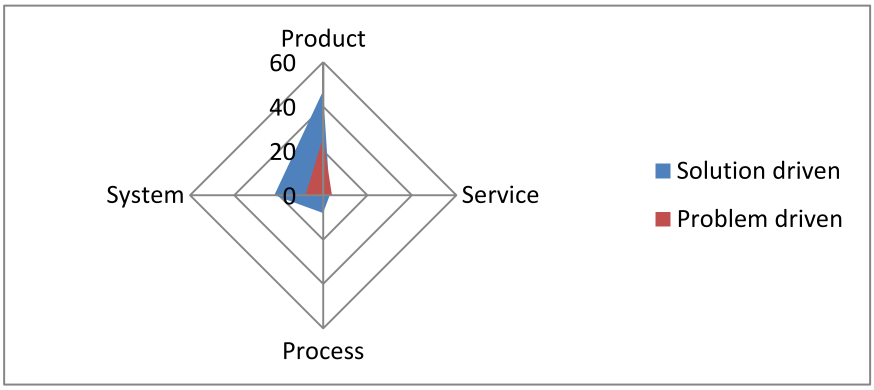
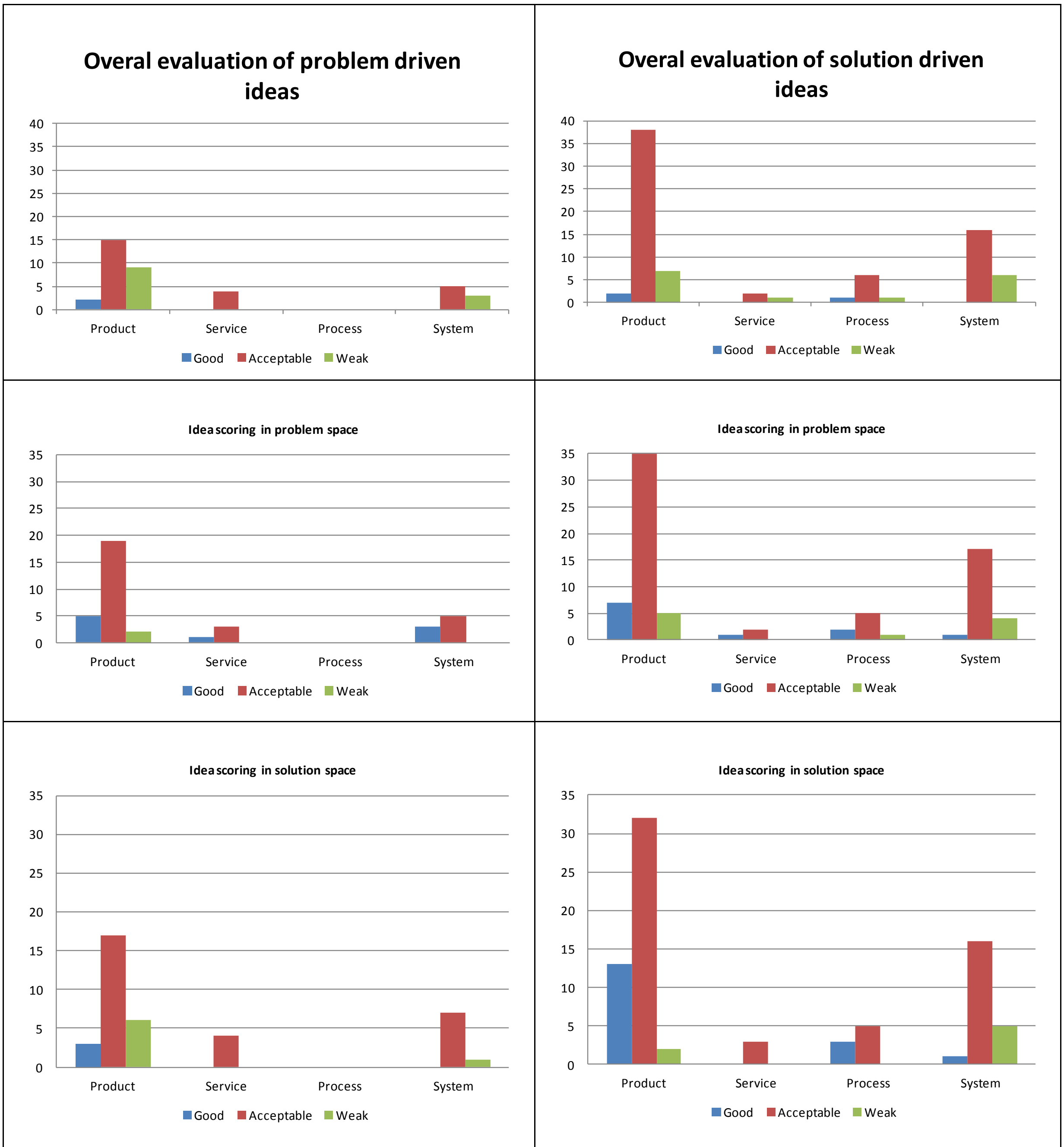


Figure 3. The distribution of final application for problem driven and solution driven ideas

Figure 4 depicts the average result of idea rating by four reviewers. The vertical axis shows the number of idea in all diagrams. In the first row, the distribution of ideas in problem driven approach and solution driven approach is given by application domain. While the concentration of the number of submitted ideas is on product through solution driven approach, a much less attention in given to product idea in problem driven approach. The second place in solution driven approach belongs to system.

In the second and third rows, the design approach is crossed with the design space. In other words, from two problem and solution driven approaches and two problem and solution spaces, four diagrams are generated in which the distribution of ideas is depicted using application domains and score categories. Contrary to the first raw diagrams, the score of problem space and solution space are used separately to show the distribution. For instance, for a good idea in first raw diagrams the sum of problem space and solution space scores should be more than 5, no matter the share of each space.

As a result, if considering the problem driven approach, the concentration of good and acceptable statements is more in problem space than in solution space.



(a) Problem driven approach (b) Solution driven approach

Figure 4. Distribution of bio-inspired ideas in approaches and in application categories

The students were let free to use their general knowledge or consult a reference for describing a mechanism undertaken by nature. In ideas submitted using problem driven approach, only 15 percent used a reference. Alternatively, 44 percent of solution driven ideas used a reference for the bio inspiration. Figure 5 shows the distribution of referenced general knowledge bio-inspired ideas in four categories of final application of solution driven approach ideas. The distribution of the whole ideas is very similar to this diagram, because of the negligible number of referenced ideas in problem driven approach.

Finally, in order to investigate the consideration given to problem and solution spaces, one way is to look at the distribution of ideas in these two spaces. However, considering only mature ideas (labeled as good idea) would be more representative than the total number, because it indicates the ideal behavior of the students of the given profile, facing with the bio-inspired design ideation exercise.

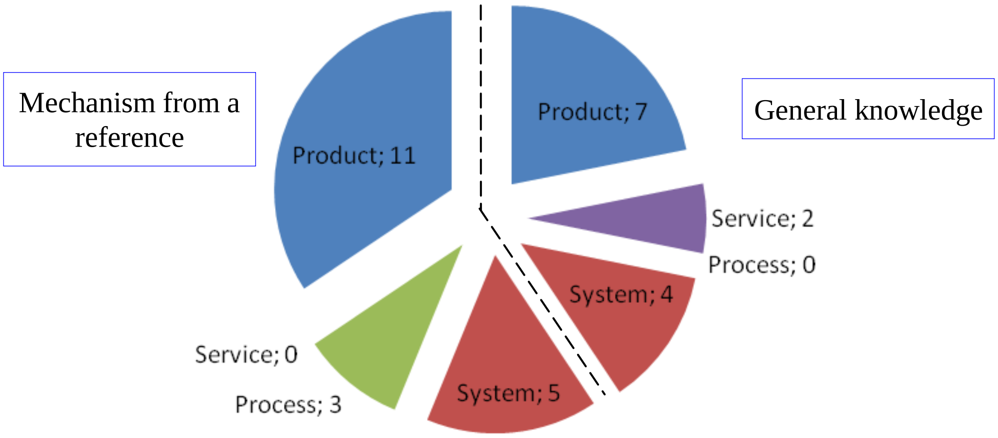


Figure 5. Distribution of referenced general knowledge bio-inspired ideas in four categories of final application

In figure 6, first diagram shows the distribution of good and acceptable ideas in problem driven and solution driven approaches. Two other diagrams show the number of only good ideas judged by the statement separately in problem space and solution space. As a result, the concentration of well formulated statements is observed rather in solution space for solution driven approach, while the distribution is almost equal in problem space for problem driven and solution driven approaches.

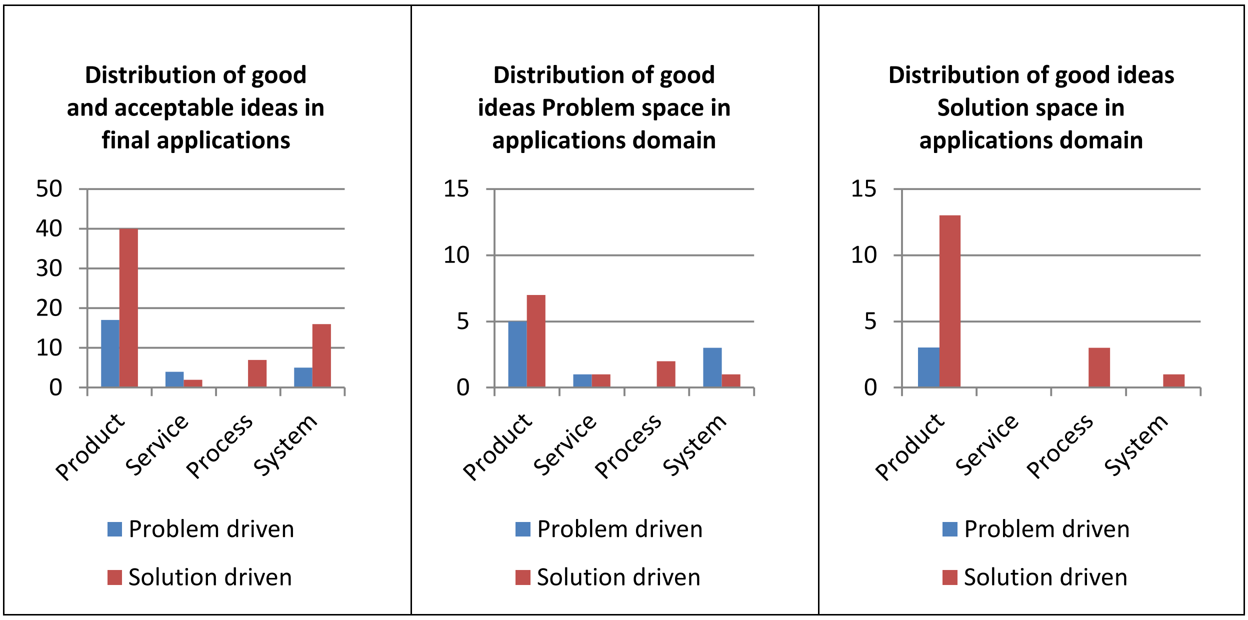


Figure 6. Distribution of good ideas over approaches and in categories

5 CONCLUSION

Understanding of how engineering student react and use bio-inspired design methods helps to improve employing this approach as an ideation step in design course. Moreover, Bio-inspired design is a growing area of design research thus methodological reflection on this approach brings advantages in theoretical aspects, as well as in practice of design. In this paper, we took a first step toward experiencing and analyzing the result of teaching bio-inspired design to last year engineering students in problem solving module. The objective was to look in detail into how students used bio-inspired design in ideation, in which domains, and of what maturity scale.

Students used both problem driven and solution driven approach to generate new ideas. Meanwhile, the experiment was designed to investigate the consideration attributed to the problem and solution spaces.
We noted the interest of students for solution driven approach, particularly from the number of good ideas, while they seem to have more difficulties to start with a problem statement and find a natural solution to solve the problem. Moreover, judging by the number and the distribution of mature ideas, it is observed that solution space is given a strong consideration in solution driven approach, while in problem driven approach the concentration is almost equally distributed between problem and solution spaces.
This study agrees with the conclusion drawn by Helms (2009) that once a biological solution is chosen, it becomes a source of design fixation, limiting the source of inspiration to that one source. Also, it is observed that the understanding and formalization of a bio inspiration is more considerable in solution driven approach than in problem driven.
The interest of the students for final application in product and system can be explained from the fact that in general engineering courses the focus of methodic education is on these two domains. However, another explication could be the lack of formalization and case demonstration of bio-inspired design method in service and process areas during the lectures.
This study is limited in several ways: in experiment design, the experiment performance, and in analyses. The design of experiment should be improved by integrating functional modeling to the ideation, with preferably predefined design subjects. The attribution of application domain should be given to the students, or, for a comparative study, students should be asked to generate a certain number of ideas in given domains. The limit of participant small number is not fundamental and can be solved by repeating the experiment in different classes. In the same way, the idea rating is better to be performed by a larger group of evaluators for avoiding biased rating.
In future works, we will observe and analyze the group work of students doing a whole project using bio inspirations in order to explore in more detail the design activities and iteration between problem and solution space within, the design process.

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