A Proposal for Biomimicry as Basis for an Integrative Pedagogy for Sustainable ID
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Introduction
The environmental and social problems that the current industrial production methods have generated in society are today well known. Furthermore, mass media and the process of globalization have influenced greatly our current lifestyles and way of thinking. Within this context, the role of industrial design (ID) in society is quite important and deals with diverse long-term responsibilities that should be taught at an early stage to design students. The education of ID must constantly be redefined to address the new challenges faced by today's designers. However, the problems originated by the industrial society cannot be solved with the same industrial thinking paradigms of the system that generated them. As such, alternative Design for Sustainability (DfS) teaching models and methods need to be developed, tested, evaluated, and refined to cater to the new challenges of design education.

The main objective of this paper is to describe and discuss a proposal for a teaching method for DfS, based on the integration of biomimicry, human needs analysis and ecodesign analysis tools. In order to develop this method, a substantial literature review included diverse Ecodesign education methods, such as the Okala Curriculum (White, St. Pierre, & Belletire, 2003). Also a number of relevant papers and books in education for sustainability and sustainable design (Birkeland, 2002; Manzini, 2006; Marinova & McGrath, 2004; Ramirez, 2004) were reviewed. Concurrently, a review of bio-inspired design literature (Benyus, 1997; Dollens, 2005) and many discussions with researchers in related design fields, provided evidence that a bio-inspired design approach that integrated the human (social), environmental and economic aspects of DfS, was worthy of further exploration. For this purpose, significant study cases from different disciplines (engineering, materials research, nanotechnology, architecture) were discussed in congresses or meetings at Kobe University (Japan), Georgia Tech University (USA), and Los Andes University (Colombia), among others. Also a close collaboration with the Biomimicry Institute provided up to date information about a relevant range of teaching strategies and state of the art case studies of biomimic design in various disciplines.

Theoretical Framework
The main elements of the theoretical proposal for the teaching and learning method here presented are summarized in the initial four diagrams that follow.

![Figure 1. Sustainability Education (Level 1 of Learning Spiral, see also Figure. 4)](image1)

![Figure 2. ID Education Diagram (Level 3 of the Learning Spiral, see also Figure. 4)](image2)

Briefly, the main issues of sustainability comprise the integration of human (social), environmental and economic aspects (Figure 1). As such, to be effective, education for sustainability should integrate, in a cross-disciplinary way, knowledge related to these three fundamental aspects, which are generally interdependent. In relation to ID education and practice (Figure 2), Ecodesign (Design for the Environment or DfE) refers specifically to the environmental considerations of design, especially in...
relation to the life cycle of the product. In other words, how the product is conceived, produced, used, and finally disposed of (or hopefully recycled), and the significant implications that these different phases have on our environment. However, DfE is only the environmental aspect of design, although sometimes it is equated with Design for Sustainability or DfS. For an integrated view of DfS, a simplified description of some elements and relationships within industrial design education that are relevant to sustainability but are usually taught independently, are illustrated in Figure 2. The main components in this diagram are: (a) human factors, related to the social aspects; (b) ecodesign, related to the environmental aspects; and finally (c) economic factors related to economic development within sustainability.

Alternatively, since the origins of human kind, people have studied nature in many different ways to find inspiration for solving their design and technology problems. History is full of examples of these approaches incorporating the relationship of nature and design, often with an artistic or technological focus. A few examples of bio-inspired design include technological inventions such as da Vinci’s projects, and Bionics, Biomechanics and Robotics, among many others. From an artistic point of view, movements such Art Nouveau, Organic Design, Biomorphism or even contemporary “blobbjects” also have a close relationship with nature. In this research, the most up-dated strategies of Biomimicry (Benyus, 1997) were chosen for the development of the teaching and learning method presented in this paper, primarily due to their relationship to sustainability. Biomimicry proposes the study of nature from a systems point of view in which all elements are interdependent. It understands nature as model, measure and mentor (Figure 3). Understanding nature as measure means respecting the limits of nature and thus respecting the principles of sustaining life in our planet. This is the main theoretical difference of Biomimicry with regards to other bio-inspired disciplines. Biomimicry theory not only explores the shapes of nature (organic shapes and biomorphism) or its mechanisms (bionics and biomechanics) but also understands nature as a system, encouraging imitation of processes and ecosystems. As such, it is currently used within disciplines such as engineering, materials science and agriculture, among others.

Finally, the integrated teaching-and-learning method for DfS proposed in this paper can be visualized as a growing spiral, in which the three previous diagrams are interrelated (Figure 4). The proposed model starts from a basis of understanding the three main pillars of sustainability. Then moving on, sustainability is viewed through the filter of biomimicry. In this second step, the use of nature as model, measure and mentor provides a link between ID and sustainability. Finally, important elements that are part of ID practice and education are interrelated with the elements of biomimicry and sustainability.

**Practical Experiments**
Employing the previously described teaching and learning model as a basis, two consecutive experimental workshops were held during the academic calendars 2006-2007 and 2007-2008 in order to test and evaluate the proposed method. The setting for these workshops was an Ecodesign and
Sustainability module taught as part of the BAID program in the School of Design and Environment at the National University of Singapore. Detailed reports of this experimental work are part of the lead author’s doctoral dissertation and will not be discussed in depth in this paper. However, a brief summary of the results and findings of these two experimental workshops is presented hereunder.

The general learning objective of this ID module was to stimulate an ethical and responsible approach of ID towards society and the environment. Lecture sessions covered a wide variety of interrelated topics. Some topics were explained by the lead author, and also by guest lecturers from other disciplines or industry. Other topics were prepared and presented by the students. In relation to the environment, a number of texts were adapted from the Okala Curriculum, as well as related bibliography such as Cradle to Cradle (McDonough & Braungart, 2002) and Industrial Ecology (Graedel & Allenby, 1995). In relation to economic aspects, extracts of the book The Ecology of Commerce (Hawken, 1993) were discussed. Finally, in relation to human needs analysis, classic (Maslow, 1943) and more recent (Max-Neef et. al., 1987) theories were studied and linked with human factors (studied also more in depth in a separate module). An interdisciplinary approach is inherent to this type of course. As such, many of the lectures, as well as some field trips and outdoor classes, were conducted with the help of students from ecology and biological sciences, who kindly volunteered to support this experimental course.

In parallel to the lectures, practical projects were developed by teams of students in order to apply the concepts studied with in the method outlined in Figure 4. Two specific strategies for undertaking these practical projects were tested over the two consecutive academic years: the strategy for the first project was based on a “biology to human needs” sequence and the second strategy on a “human needs to biology” sequence. The details of these workshops follow below.

**Experimental Workshop 1 (WS1): Biology to Human Needs**

The practical design project was developed by groups of three students during thirteen weeks of the course module, in order to apply the design strategy summarized in the flowchart of Figure 5. The four prescribed steps followed by the students to finally arrive to a design solution, were: 1. biomimetic analysis, 2. biomimetic solution, 3. human problem analysis, and 4. ecodesign analysis, respectively.

![Figure 5. Workflow of WS1.](image)

**Results of WS1**

Nine groups of students analyzed the following natural elements: (a) Tendrils, (b) Dragonfly Wings, (c) Seashell, (d) Ant, (e) Bat, (f) Pill Bug, (g) Aloe Vera, (h) Snail Shell, (i) Octopus Suckers. Some very interesting results were proposed by the various student groups: the two most advanced and well-developed projects are shown in Figures 6 and 7.
Experimental Workshop 2 (WS2): Human Needs to Biology

In WS2, a different batch of students again worked in groups of three. The workflow of this strategy is summarized in Figure 8. The five prescribed steps followed by the students were the same as in the previous workshop, but in a different order. This project started with human problem analysis, and then proceeded to biomimetic analysis, biomimetic solution, eco-design analysis and finally the proposed design solution.

Figure 8. Workflow of WS2.

Results of WS2


Figure 9: Chopstick Repurposing developed from the analysis of bird nests and cycles in nature.
In this case, different bird nest weaving techniques provided inspiration to develop handcrafted products for re-cycling discarded disposable wooden chopsticks. (Students: Yvonne Chua, Yong Lin and Sophie Maiko Thornander).

Figure 10: A shoebox that saves 30% cardboard and can be re-used as a shoe hanger or rack, inspired by cocoons.
The analysis this group made of existing shoe boxes in the market, combined with a biomimic analysis of packages in nature (especially cocoons) proved very useful for the final proposal. (By students Toh Teck Chye and Ang Wei Quan).

Evaluation of WS1 and WS2

In order to evaluate the two workshops, a questionnaire, to be answered individually and anonymously, was handed to the students of both courses. It is timely to clarify that a direct quantitative comparison of both workshops is not possible, as no control group was used and the students were different in both workshops (thus, their skills and opinion could vary and influence the results). Also, student feedback cannot be considered conclusive in terms of the effectiveness of a teaching method, except in broad qualitative terms. However, the analysis of the feedback provides important qualitative information useful in appreciating students’ perceptions of the course, and thus identifying areas for possible improvement. As such, similar student feedback is also used by diverse universities (as is the case of NUS) to evaluate their teaching staff and programs.

The survey questionnaire (prepared ad hoc for this research) was composed of twelve questions that were to be graded from 1 to 5 according to the following parameters: 1, strongly disagree; 2, disagree; 3, neither agree nor disagree; 4, agree; 5, strongly agree. The survey for WS1 was answered by 24 students, while the survey for WS2 was answered by 26 students. The data in the following table show the results for each workshop in the following order: average of WS1, standard deviation of WS1, average WS2 and finally standard deviation of WS2.

<table>
<thead>
<tr>
<th>Question</th>
<th>Av. WS1</th>
<th>Sd. WS1</th>
<th>Av. WS2</th>
<th>Sd. WS2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The course fulfilled your expectations and was coherent to the original plan.</td>
<td>3.42</td>
<td>0.86</td>
<td>3.31</td>
<td>0.91</td>
</tr>
<tr>
<td>2. The course was interesting, dynamic, and enjoyable.</td>
<td>3.92</td>
<td>0.86</td>
<td>3.62</td>
<td>0.68</td>
</tr>
<tr>
<td>3. The balance between lecture and practical exercise was good.</td>
<td>3.17</td>
<td>0.94</td>
<td>3.46</td>
<td>0.89</td>
</tr>
<tr>
<td>4. The lectures and educational material were easy to understand.</td>
<td>3.54</td>
<td>0.71</td>
<td>3.46</td>
<td>0.69</td>
</tr>
<tr>
<td>5. The practical exercise was easy to develop according to the information received.</td>
<td>2.92</td>
<td>0.95</td>
<td>2.88</td>
<td>1.01</td>
</tr>
<tr>
<td>6. The level of difficulty of the practical exercise was appropriate.</td>
<td>3.58</td>
<td>0.76</td>
<td>3.08</td>
<td>1.11</td>
</tr>
<tr>
<td>7. The workload was manageable.</td>
<td>3.42</td>
<td>0.95</td>
<td>2.77</td>
<td>0.89</td>
</tr>
<tr>
<td>8. The course is suitable for the second year undergraduate level.</td>
<td>4.09</td>
<td>0.65</td>
<td>3.65</td>
<td>0.78</td>
</tr>
<tr>
<td>9. At the end of the course, there is a clear understanding of the basic themes.</td>
<td>4.13</td>
<td>0.53</td>
<td>3.92</td>
<td>0.67</td>
</tr>
<tr>
<td>10. There is a clear link between your profession and the course.</td>
<td>4.50</td>
<td>0.71</td>
<td>4.27</td>
<td>0.81</td>
</tr>
<tr>
<td>11. The material studied in the course is useful for your future professional life.</td>
<td>4.21</td>
<td>0.71</td>
<td>3.81</td>
<td>0.96</td>
</tr>
<tr>
<td>12. The information and methodology is valuable and can be applied in future projects.</td>
<td>4.25</td>
<td>0.60</td>
<td>4.00</td>
<td>0.78</td>
</tr>
</tbody>
</table>
In terms of learning outcomes, when the group who took WS2 was asked if the module had enhanced their critical thinking skills, 65% of the students answered positively. Furthermore, 8% also mentioned that the course “helped them to think out of the box” and to “look at things from many different points of view,” which suggests an improvement in creative thinking skills.

Finally, answers to the question: “What was the most important thing you learned in this course?” also provide some insight into what the students mostly remembered from the module. Some of the most relevant answers by the students were:

“Sustainability, too, is not only about saving the environment. It has social and economic factors as well. That is because even if we designers do our part in making ecodesign possible, there has to be a market for this as well, so the human behavior and how receptive they are to such designs are equally crucial in making the entire sustainability issue.”

“In order to achieve a sustainable way of life we should study nature and imitate natural elements and systems. Nature has already solved many problems that could be related to human needs.”

“What I have learned from this module is to not just look at a product by itself, but its whole process. For instance its life cycle: manufacturing process, disposal, and so on. I feel that every one of us really has the responsibility to save the planet.”

Discussion

The experimental results from the noted design projects indicate reasonably strongly that the teaching method proposed in this paper can stimulate industrial design students to generate innovative and sustainable designs inspired by nature. Also, results of the feedback from the students suggest that their awareness of sustainability issues and their relationship with ID increased substantially. According to the students’ evaluation of the course conducted by the lecturer (and which was compared to and further validated with the survey conducted by the university), the two most positive aspects of the workshops developed were: (a) the link between the method and the industrial design process and the applicability of the method in future projects, and (b) an understanding of the topics of sustainability and ecodesign after the course. On the other hand, items that got the lowest scores and should be further refined were: (a) the workload of such a course, especially in relation to the balance between lecture and time for guidance for the practical projects, and (b) the clarity and simplicity of the method for the practical project.

Comparing WS1 the “biology to human needs” strategy developed in the first run of the course with the second run WS2 “human needs to biology” strategy, evaluation and discussions with the students suggested that the second strategy proved more difficult for the students to follow and apply. This observation is consistent with observations by other researchers in the field of biomimicry education (Hoeller, 2006). It is also important to note that the process followed in WS1 is more related to traditional “bionics” or “bio-inspired” approaches where the designer starts without any constraints with an observation of nature, trying later to find practical application to his findings. WS2 started from human problems and real necessities, thus providing real-world constraints and projects with greater complexity for the students. However, the process of WS2 is closer to the real challenges an ID would face in his professional life and should therefore be encouraged more widely.

In both WS1 and WS 2, although a systems thinking was encouraged, with a strong focus in the design of process or systems (and many cycles in nature were used as reference of close loop cycles), many of the final results showed some sort of form analogy with natural or organic elements. This is because mimicking form and function in nature is easier than mimicking processes or ecosystems. However, it can also be a consequence of the student’s eagerness to make clearly evident the use of nature as inspiration through a literal form analogy.

In relation to the lectures within the course, presentations of topics by the students are considered of great educational importance due to the self-research involved and the training in visual communication and oral presentation skills. However, it is also evident that this activity increases the workload on the
students. Some students expressed to be very “skeptical” of the quality of the information presented by their peers, and requested more lectures by the lecturer, even though each presentation was fully discussed and complemented in class.

In relation to the practical projects, some students mentioned as a weakness of the projects, what they felt as “great difficulty and complexity,” “too much effort required” and a “not well-defined methodology that was confusing.” However, intentionally the students had to organize their own work teams, define their own problems, and even sometimes propose their own project method based on the generic design methods (Bonollo & Green, 2004) studied in other modules. Although it is evident that these decisions might be complex for year-two undergraduate students (average age: 20 for females, 23 for males within the studied context); the ability to choose a relevant topic or to find a suitable design problem is fundamental for designers. Although demanding, the choice of their own projects and methodologies also provided critical thinking training, while making the students aware of the implications of their own design decisions. On a final note on this aspect, it is timely to clarify that due to the integrative and cross-disciplinary nature of such a course, it is indeed complex and time consuming. However, cultural and pre-universitary educational backgrounds of the students influence their preparation for such a learning system. In the case of Asian students (mainly Japanese and Singaporean observed during this research) as compared to western students, it was noted that while group–work skills are strongly developed in Asian education, individualistic skills such as discussion abilities or self-guidance seem to be less emphasized. This seems to affect the perception of complexity and difficulty of such learning method within the tested groups of Asian students.

Finally, in terms of the positioning of such a course within the curriculum of a four-year undergraduate ID program, most students agreed that it was suitable in the 2nd year (3rd semester of 8). Some students did comment that due to the complexity of the projects and the importance of the topic, they would rather develop such a project in depth as part of a main design studio. Discussions with design educators from different backgrounds suggest that a DfS course like the one described here should if possible be linked to a design studio, and preferably be taught in a higher level due to its complexity. An interesting indicator that supports this opinion is the increasing variety of postgraduate courses at masters and doctoral level related to sustainable design, which are currently offered in many universities around the world. However, it is also true that the thinking skills related to DfS should be acquired as early as possible, and thus the possibility of a DfS module taught progressively at diverse levels should be further explored.

Conclusions and Further Research
Cross-disciplinary studies are very important in professions such as design, as they stimulate creative and critical thinking. An integrated teaching and learning method that combines biomimicry, ecodesign tools and human needs analysis can provide fundamental knowledge for design for sustainability through the integration of social, economic and environmental aspects. However, although stimulating and rewarding, such a process can prove complex and time-consuming for the lecturers as well as for the students and should be further refined.

Further short-term research will be conducted in order to simplify the methods and reduce the workload without sacrificing important content and learning activities. A third experimental workshop, WS3, will be undertaken in academic year 2008-2009. It will combine both strategies tested in WS1 and WS2 in the context of the teaching and learning method described in this paper. The main project will continue to explore the “human needs to biology” strategy, due to its relationship with the common challenges faced by design practitioners. However, the “biology to human needs” strategy will also be used in a short session as a sensitizing tool to explore creatively the many possible ideas from nature. Further long term research aims to refine the teaching method, eventually expanding it to a complete ID studio course, a progressive module or even as basis for a postgraduate cross-disciplinary research.

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References


