INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION
6 & 7 SEPTEMBER 2018, DYSON SCHOOL OF DESIGN ENGINEERING, IMPERIAL COLLEGE, LONDON, UNITED KINGDOM

DESIGN TOOLS IN MATERIALS TEACHING: BRIDGING THE GAP BETWEEN THEORETICAL KNOWLEDGE AND PROFESSIONAL PRACTICE

Agnese PISELLI[1, 2], Caterina DASTOLI[3], Romina SANTI[1] and Barbara DEL CURTO[1, 2]
[1]INSTM, National Interuniversity Consortium of Materials Science and Technology, Italy
[2]Chemistry, Material and Chemical Engineering Department "Giulio Natta", Politecnico di Milano, Italy
[3]Design Department, Politecnico di Milano, Italy

ABSTRACT
The industrial panorama increasingly calls for multidisciplinary design professionals who integrate design thinking and engineering knowledge in developing new products and services. Taking into account this need, a practical experience was designed to combine the traditional theoretical framework of materials selection with industrial case studies application.
This work explores the results of five one-week workshops conducted in collaboration with materials producers and manufacturing companies. Following the Ashby's method, students applied a "Reverse materials selection" process to identify the applied materials and manufacturing solutions, without having any information about the current employed solutions. The students, then, were called to design innovative concepts by changing the materials the components were made of.
The outcomes of this research are 48 product concepts, elaborated by 154 design students from 2013 to 2017. The works have been evaluated according to the materials selection process applied and the possible levers of material-driven innovation that emerged from the analysis (e.g., technological, functional or aesthetical/sensorial).
From this, work emerges that materials selection could be a powerful driver for materials and products innovation. The proposed workshop methodology represents a win-win strategy for both university and industry: it improves the education quality, allowing students to acquire a professional-based knowledge about the materials and technologies most used in specific market contexts. The bottom-up approach helps designers in producing a more "aware design" and in exploiting the potentials and limits of the solutions already employed by the industry, envisioning the possible application of promising materials and technological advances.

Keywords: Materials selection, Materials knowledge, Design education, University-industry collaboration, Material-Driven Innovation.

1 INTRODUCTION

In the rapidly-evolving industry, there is a growing need for multidisciplinary designers that could lower the gap between theoretical knowledge and professional practice [1] by integrating design thinking and technical skills to develop new products, services and experiences. In nurturing an industrial system that emphasises design innovation [2], new professionals must have experience with user-centred design, user-interaction, human factors [3], computer-aided tools, prototyping by new manufacturing technologies, product life-cycle management [4] and materials knowledge [5]. Taking into account these industrial needs, the Design School of Politecnico di Milano introduced the Master Degree programme in "Design & Engineering" in 2004. Through the co-operation in the educational project of the disciplinary areas of "Design", "Mechanical Engineering" and "Materials Engineering", Design & Engineering graduates are able to manage product development skills that cover technical, expressive and material features of the project. In new product development (NPD) [6], the selection of the most suitable material for a given component represents a fundamental decision-making process. Materials selection involves seeking the best compromise between the component's design requirements and its functional properties [7]. Materials selection has become a hybrid field of

research. Scientists, materials engineers and industrial designers work together in investigating different materials properties: technical, manufacturing and economical properties, ecological aspects, sensory criteria and perceptions characteristics [8].
In teaching materials science fundamentals in Design & Engineering, different courses are proposed, among all, "Materials selection Criteria" and "Nanotechnology and Functional Materials For Design". The first course provided introduces students to the fundamentals of materials engineering: materials classes and properties (physical, mechanical, thermal, optical, etc.), and their implication into product development following the method of selection of the Professor Michael Ashby [9]. "Nanotechnology and Functional Materials For Design" course has the aim to develop the interest of future designers to innovative technologies and materials, and to their expressive and sensorial dimension [10]. Taking advantage from the collaboration with material producers and industrial partners from the household appliances, lighting, fashion and accessories field, the traditional theoretical framework of "Materials Selection Criteria" course was combined with a practical experience that aims to apply the acquired knowledge in real industrial case studies. This paper explores the results of five workshops, conducted from A.Y. 2013/2014 to A.Y. 2016/2017, and proposes case study method in design-based material selection teaching.

2 MATERIALS SELECTION WORKSHOPS

This research exploited the potentiality of "materials selection workshops", practical experiences that last 5-days (40 hours) and are conducted in collaboration with international manufacturers. Through a case-study based approach [11], the practical experience aims to integrate active and problem-based learning to lower the gap between theoretical fundamentals of materials selection (mainly technical and manufacturing properties of materials), and industrial practice. The materials selection case study is characterised by specific constraints and the students, grouped in small teams, play the role of practitioners in this situation, in order to improve their problem-solving skills [12].

2.1 Brief

Depending on the company involved, the workshop can be elaborated in two typologies:

Type A. Manufacturing company

Type B. Material producer/supplier

The objective of workshop A is the redesign of a product, or its components, based on material manufacturing process replacement. In workshop A, students had the opportunity to visit the company and its production line. This experience allowed to better investigate the industry know-how, in terms of processes, technologies and materials currently employed in the production. In the second type of workshop (B), students were called to explore the properties of a specific material and the possible contexts of application. The aim of the activity is to design of an innovative product concept that integrates it. Before leading the activity, students are provided with an introduction to the main properties of materials (physical, mechanical, thermal, optical) and manufacturing processes, together with an overview on the features of the most commonly used materials selection software both in the industry and in the academic context (i.e., CES EduPack) [13].

Table 1. Workshop framework

Monday	Tuesday	Wednesday	Thursday	Friday
CES exercise + Brief recap	*STEP 2*	*STEP 2*	*STEP 3*	*STEP 3*
STEP 1 presentation	*STEP 2*	STEP 2 presentation	*STEP 3*	Final presentation

2.2 Workshop details

The workshop has mandatory attendance and passing the exam consists in a final presentation, where students discuss about the outcomes achieved (product concept). The work is evaluated using a three marks scale (A, B, C), then converted in a 30-point scale, according to the academic grading system used in Italy. The assessment criteria considers the applied materials selection process, the detail of components and context analysis and the possible levers of material-driven innovation that emerged (e.g., technological, functional or aesthetical/sensorial). Further information on the design approach and critical issues were registered through qualitative interviews, whose structure is described in Piselli, Simonato and Curto (2016) and Dastoli et al. (2017) works. The participants are divided in teams of 2 to 4 person and the workshop was attended by a variable range of students, between 16 and 45. Workshop's students were characterized by a different background (Industrial Design, Fashion Design, Mechanical Engineering, Materials Engineering, Engineering Management, etc.).

2.3 STEP 1

In workshop A, each group is provided with a 3D assembly of a product. Appliances out of production were selected in order to avoid students from information-seeking from the internet, such as on materials, finishes and production processes. The output for the first step (*Product analysis*) is an exploded view drawing that highlights the main components of the artifact and the Bill Of Materials (BOM) [8,15] (Fig. 1). Participants of workshop B are provided with technical and manufacturing information about the material produced by the company (*Material analysis*). By the end of the first day, students had to select a specific application field to focus on, considering possible issues to be solved thanks to the implementation of the material under evaluation [14,16] (Fig. 2).

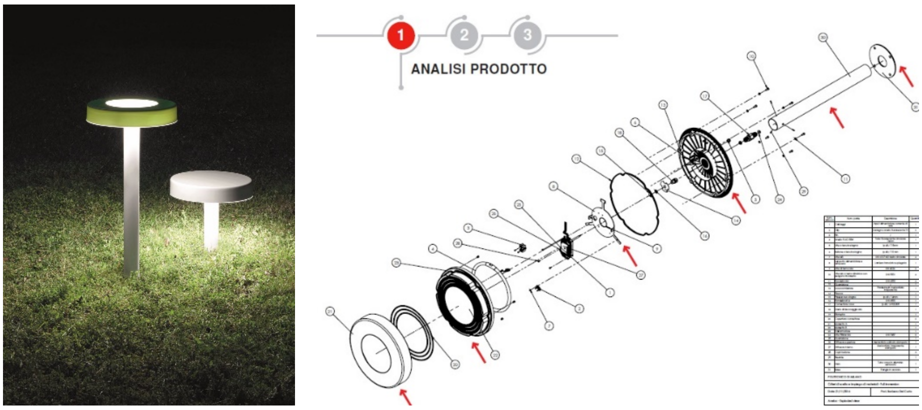

Figure 1. Workshop (A) – Product (left) and product analysis output (right)

Figure 2. Workshop (B) – Material (left) and application field moodboard (right)

2.4 STEP 2

Inspired by the studies on reverse engineering practice as D/A/A (Disassemble, Analyse, Assemble) activities [17], the "components analysis" step or "Reverse materials selection" characterises only the workshop type A. By selecting only some parts for each product from the previous step, at this stage students are required to speculate on components' function, constraints and objectives, following the Ashby's selection process [9]. The working condition of the components are investigated and mechanical, thermal, optical properties, as well as durability of materials are generally considered to identify two possible material candidates. The output of this step is a presentation and report in which the process of "Reverse materials selection" is described. At the end of the presentation, the real manufacturing processes and materials are revealed to students.

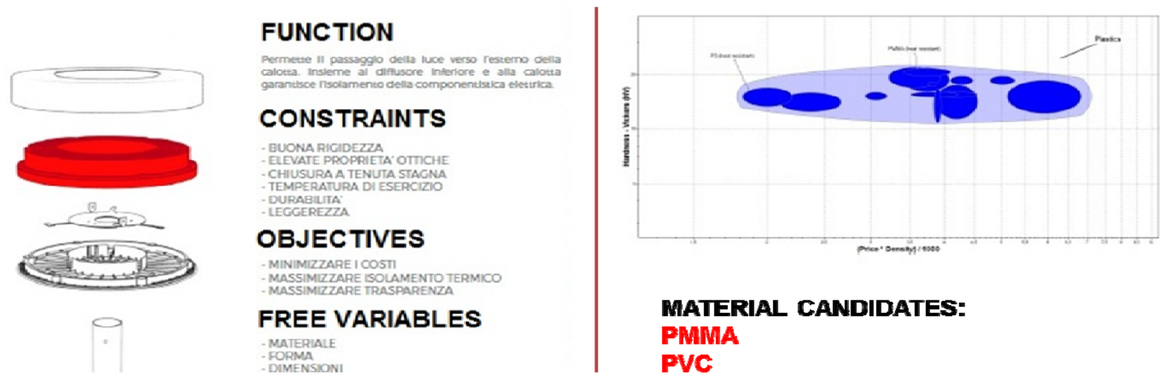

Figure 3. Workshop (A) – Component analysis and candidate materials (PMMA and PVC)

In workshop B, the second step involves the development of two or three product concept that integrate the material object of the investigation. The output is a presentation of preliminary conceptboard made by sketches and functional details.

2.5 STEP 3

After selecting suitable materials and manufacturing technologies for the analysed components, participants of workshop A are called to focus on the component of the product that could be more affected by a material substitution. Based on a materials selection-driven approach, they will redesign one or more components that will increase the product's performances and functionality (*technical/functional innovation*), or usability and perceived qualities (*aesthetical/sensorial innovation*). The output of this step is a final presentation and a written report that describes the product scenario, a short market/competitor analysis, and the selection process for material and processing change, leading to product innovation.

Figure 4. Workshop (A) - Innovation by the change of the light diffuser shape and material

By the end of workshop B, each group presents a final concept, explaining the advantages of their solution, compared to the currently employed in the market, and detailing the product features. Also in this case, the output is a 15 minutes presentation and a report, in which the context research and the design process together with the feasibility of the product concept are elaborated.

3 RESULTS

The outcomes of the five worshop are 48 product concepts, elaborated by 154 design students. The details of the conducted workshops are presented in Table 2 and in the following paragraphs.

- *Workshop type A*

A1. Lighting design company [15]
A2. Professional kitchen/laundry appliances [8]
A3. Lighting design company

- *Workshop type B*

B1. Shape memory alloy (SMA) producer [16]
B2. Smart textile producer [14]

Figure 5. Workshop (B) – Concept for the application of the textile in a novel industrial field

The goal of the workshop was achieved and positive results were obtained in terms of number of concept generated and of their quality. All the concepts, indeed, met the minimum criteria (C grade), the 45.8% of them was judged as excellent (A grade), while the 35.4% of the outputs were evaluated as good (B grade). The level of technical or aesthetical innovation was qualitatively evaluated with the support of the company's experts, who participated at the workshop as supervisors. This assessment was based on the evaluation of different criteria as manufacturing feasibility, focus on product usability, attractiveness of aesthetics, concept novelty among the solutions already present on the market. At least one outstanding solution, evaluated in a 30-point scale as "30 cum laude", was presented in each workshop.

Table 2. Workshop results

Type	Object of analysis	Students	Groups	Academic grading	Company grading	Concept	Innovation type
A1	10 lamps	38	10	A (4) B (4) C (2)	A (5) B (4) C (1)	10 components redesign	8 technical/functional 2 aesthetical/sensorial
A2	5 professional kitchen modules	23	7	A (2) B (2) C (3)	A (3) B (4) C (0)	7 components redesign	5 technical/functional 2 aesthetical/sensorial
A3	10 lamps	30	10	A (6) B (3) C (1)	A (7) B (3) C (0)	10 components redesign	8 technical/functional 2 aesthetical/sensorial
B1	3 SMA alloys semi-finished products (spring, wire, strip)	45	12	A (6) B (4) C (2)	A (5) B (6) C (1)	12 concepts: *Household appliance, Lighting, Biomedical, Sport, Fashion, Robot Packaging*	11 technical/functional 1 aesthetical/sensorial
B2	Optical Fibre Weaving	18	9	A (4) B (4) C (1)	A (4) B (4) C (1)	9 concepts: *Household appliance, Fashion, Furniture*	9 aesthetical/sensorial

4 DISCUSSION AND CONCLUSIONS

Design-based learning tools allow teaching theoretical foundations while empowering the development of practical skills focused on the product (e.g., sketching, prototyping, form and function concept generation, aesthetics, etc.) [2,18,19]. From this, work emerges that practical experiences based on materials selection could be drivers for innovation in the manufacturing industry and in the material production sector. The excellent concepts elaborated by students testify that a bottom-up approach can help students in producing a "more aware design", which is closer to new industrial challenges. The proposed methodology represents a win-win strategy for both university and industry. The surveys, conducted at the end of the five-day workshop and whose structure is described in Piselli, Simonato and Del Curto (2016), confirmed that the practical experience improves the education quality. In particular, students affirmed that practicing materials selection on real industrial case studies allows to acquire a professional-based knowledge about the materials and technologies most used in specific market contexts. Moreover, in our opinion, “Reverse materials selection” phase supports students to learn the principles behind the design of the product under investigation, detecting advantages and limits of the materials choice for each component, along with possible ways to redesign it to improve its performances and aesthetics [17]. The workshop framework described in this paper represents an effective instrument also for companies, as it enables to gather innovative ideas for a product redesign driven by materials selection [8] and to achieve better research outputs, envisioning new applications of promising materials and technological advances. At last, this practical experience can strenghten strategic partnerships among universities and industry by the company’s involvement into teaching and research activities (e.g., funded projects, thesis, etc.). Improvements for extending this method also to other theoretical design courses as well as the integration of the qualitative instrument of surveys is currentluy under evaluation. Moreover, a new grading system for an easier evaluation of concept innovation should be further investigated.

REFERENCES

[1] R.S. Adams, S.R. Daly, L.M. Mann, G.D. Alba, Being a professional: Three lenses into design thinking, acting, and being, *Des. Stud.* 32 (2011) 588–607. doi:10.1016/j.destud.2011.07.004.

[2] K. Straker, C. Wrigley, The Educational Design Ladder: Creation of a Multi-Discipline Design Thinking Programme. In *Proceedings of NordDesign 2014*, Espoo, August 2014, pp. 65–74.

[3] L. Rampino, *Design: between scientific method and project praxis*, Franco Angeli, Milano, 2012.

[4] M. Aurisicchio, R. Bracewell, Capturing an integrated design information space, *J. Eng. Des.* 24 (2013) 397–428.

[5] L. Veelaert, E. Du Bois, K. Ragaert, S. Hubo, K. Van Kets, Bridging design and engineering in terms of materials selection. In *Proc. 7th Int. Polym. Mould. Innov. Conf.* (2016) 319–326.

[6] Z. Taha, H. Alli, S.H.A. Rashid, Users Involvement in New Product Development Process: A Designers’ Perspectives, *Ind. Eng. Manag. Syst.* 10 (2011) 191–196.

[7] A. Piselli, W. Baxter, M. Simonato, B. Del Curto, M. Aurisicchio, Development and evaluation of a methodology to integrate technical and sensorial properties in materials selection, *Mater. Des.* 153 (2018). doi:10.1016/j.matdes.2018.04.081.

[8] A. Piselli, M. Simonato, B. Del Curto, Improving The Learning Process In Materials Selection: The Role Of Context In Choosing Material Solutions. In *Proc. 10th IATED*, Valencia 2016, pp. 6713–6722. doi:10.21125/inted.2016.0582.

[9] M. Ashby, *Material selection in mechanical design*, Butterworth-Heinemann, Cambridge, 1992.

[10] E. Karana, O. Pedgley, V. Rognoli, A. Korsunsky, Emerging material experiences, *Mater. Des.* 90 (2016) 1248–1250. doi:10.1016/j.matdes.2015.07.042.

[11] M.G. Burke, J.D. Carter, A.W. Hughey, M.G. Burke, J.D. Carter, A.W. Hughey, The use of case study competitions to prepare students for the world of work, *Industry & Higher Education*, 27 (2013) 157–162.

[12] N.A. Iahad, M. Mirabolghasemi, N.H. Mustaffa, M. Shafie, A. Latif, Y. Buntat, Student Perception of Using Case Study as a Teaching Method, *Procedia - Soc. Behav. Sci.* 93 (2013) 2200–2204.

[13] Granta Design Ltd., Cambridge Engineering Selector software (CES), (2017).

[14] C. Dastoli, R. Santi, A. Piselli, M.G. Soldati, B. Del Curto, “ Filo Di Luce ”, Workshop Experience For Fashion And Product Designers Different Approach Analysis Related To An Innovative Textile Material Application. In *Proc. 10thICERI*, Seville 2017, pp. 7754–7762.

[15] A. Piselli, P. Garbagnoli, B. Del Curto, Innovative light shapes: an educational experience on materials and manufacturing technologies’ selection. In *9th IATED*, Madrid 2015, pp. 3748-58.

[16] E. Lefebvre, A. Piselli, B. Del Curto, Smartdesign: A Workshop On Shape Memory Alloys. In *EDULEARN15*, Barcelona 2015, pp. 5381–5388.

[17] H. Rad Reverse Engineering as a Learning Tool in Design Process. In *ASEE Annu. Conf. Expo.,* San Antonio - Texas 2012, pp. 1–13.

[18] O.O. Efer, Industrial design: the roles and factors of aesthetics, modeling, styling, product brand and branding in design/design education, *Rev. Artist. Educ.* (2017) 186–199.

[19] C. Telenko, K. Wood, K. Otto, M. Rajesh Elara, S. Foong, K.L. Pey, U.-X. Tan, Designettes : An Approach to Multidisciplinary Engineering Design Education, *J. Mech. Des.* 138 (2016) 1–11.