

INVIGORATING INDUSTRIAL DESIGN MATERIALS AND MANUFACTURING EDUCATION

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Materials and manufacturing are vitally important subjects for industrial designers, being the means by which virtual products are turned to physical reality. Historically materials and manufacturing education has been dominated by engineering approaches, which often are too technical and poorly suited to the human-centred concerns of industrial designers. For example, materials selection for product function/performance is well established, but selection for product expression/personality is underdeveloped. Recently a body of new research has emerged taking a humanistic perspective to the selection of materials for industrially manufactured products. The common point is to articulate ways in which designers can use materials to affect people's experiences of products on aesthetic, meaning and emotional levels, within a wider context of product differentiation, branding, and other commercial imperatives. Accompanying this new body of research is a need to examine implications for industrial design materials and manufacturing education. This article presents a case for pedagogical change, to achieve better alignment with current and future practices of industry. Research data were derived from literature reviews, analysis of interview data with designers, and a case study to develop and evaluate materials and manufacturing training on the undergraduate industrial design programme at Middle East Technical University, Turkey. Four educational initiatives are proposed to invigorate industrial design materials and manufacturing education: (i) echo professional practices regarding the range of subjects taught and the contexts for decision-making; (ii) develop understanding of materials experience, focusing especially on sensorial and intangible qualities of materials and embracing technical and non-technical languages to teach material properties; (iii) use material and product samples as teaching resources and consider adopting 'learning through making' strategies; and (iv) instil systematic material selection methods for both utilitarian and expressive uses of materials.

INTRODUCTION

A grounding in materials and manufacturing is crucial in the training of industrial design students, as demonstrated by the wealth of materials and manufacturing content on degree programmes worldwide. Artefacts proposed by designers are made real through the use of materials and industrial manufacturing processes. Put another way, materials are the substances from which physical products are made. As Doordan (2003) notes, the history of materials is closely tied to the history of civilizations and of technological advances to artefacts. Materials continue to exert a central role in affecting the form, function and experiences gained from a product. However, the relationship and responsibilities that industrial designers have with, and for, materials are changing.

It has been long known that industrial designers' concern for materials and manufacturing selection is motivated not only by achieving product utility but also to leave a more general positive impression on people (Christensen, 1992; Sweet, 1999). The study of descriptive and associative characteristics of materials that transcend material physical properties was a pioneering aspect of Manzini's work (1986) and emerged as a global research interest from the early 2000s (e.g. Ashby and Johnson, 2003; Ferrante et al., 2000; Hodgson and Harper, 2004; Jee and Kang, 2001; Ljunberg and Edwards, 2003; Sapuan, 2001).

Building upon these studies in recent years has been an important body of research that articulates how materials selection for industrial design is shifting from a technical subject to one that is principally user-centred (Karana, 2009; van Kesteren et al., 2007; Lefteri, 2005; Rognoli and Levi, 2004; Zuo et al., 2004). To put it differently, materials selection in industrial design is becoming 'softer' and more humanized, aligned to the contemporary goal of achieving pleasurable experiences from products (Schifferstein and Hekkert, 2007).

The idea of 'soft' and 'hard' approaches to materials selection reflects the general polarisation of undergraduate product design education in universities: between departments of industrial or 3D design ('softer') and departments of mechanical, manufacturing, systems, and other branches of engineering ('harder'). A few exceptions can be found, notably hybrid B.Sc. or B.Eng. programmes offered by university departments that fuse industrial design with mechanical and electronic engineering content, for example at the universities of Loughborough and Brunel (UK), and at TUDelft (the Netherlands). Nevertheless, despite the presence of such crossover programmes, the lasting observation is that engineers are taught to be more technically astute than industrial designers (Pace, 1997). This is not so surprising, if it is accepted that the prerogative of design engineers is to design products that fit other products and operate in certain environments, whilst the prerogative of industrial designers is to design products that have a special connection to their users: physically, cognitively, personally, emotionally, culturally etc.

As a consequence of these contrasting professional perspectives, serious discussions are warranted over the kinds of materials and manufacturing knowledge and skills each profession should be educated with. For this article, the focus is materials and manufacturing training on undergraduate industrial design programmes that do not have elevated engineering content. These form the majority of industrial design programmes worldwide, aiming to graduate students capable of designing products that

would fit Conran's (1993, 8) description of good industrial design: products that are desirable for people "...to own, use and behold". Against this backdrop, two research questions (RQs) were posed that sought to uncover how the shift from a technical subject to a user-centred subject can affect the teaching of materials to industrial designers.

RQ1. What elements of industrial design materials and manufacturing course content / delivery ought to be improved / supplemented / removed, and why?

RQ2. Can a positive student experience be obtained from an industrial design materials and manufacturing course amended to the recommendations from RQ1?

The work extends preliminary findings into the knowledge and skills trainee industrial designers are recommended to possess so that they may make informed decisions about product materials and manufacturing (Pedgley and Norman, 2007). It should be acknowledged that materials and manufacturing is a very wide-ranging subject area. Despite some designers' calls to the contrary (Pedgley, 1999), a newly graduating student cannot be expected to know how to create any form, in any quantity, to any quality, in any material. Educational circumstances dictate that course content must be very carefully chosen to make best use of limited teaching time.

The responses to RQ1 -gained through literature and a partial reanalysis of the author's doctoral data- were anticipated to reveal core and peripheral materials knowledge and skills necessary for industrial design. To answer RQ2, a case study was made concerning the overhaul of the compulsory second year course 'ID236 Manufacturing Materials', offered within the Bachelor of Industrial Design programme at Middle East Technical University, Ankara, Turkey.

APPROACHES TO TEACHING MATERIALS AND MANUFACTURING

From the literature two basic approaches to teaching materials and manufacturing to industrial designers can be discerned: 'top-down' and 'bottom-up'. Furthermore, the affiliation of course tutors either to the host department (e.g. industrial design) or to an 'outsourced' department (e.g. engineering, materials) is likely to affect the educational experience for students, as will shortly be described.

Top-Down Versus Bottom-Up Teaching

The distinction between top-down and bottom-up teaching for materials is well articulated in the Myerson report (1991), which was concerned with technological change and its impact on industrial design education in the 1990s. Myerson explains that engineering usually puts emphasis on learning principles by rote first and applying them later (bottom-up), whereas industrial design usually puts emphasis on learning principles via their practical application in design projects (top-down).

The latter is sometimes referred to as a designerly approach, studio-based teaching or project-led instruction. Project-led instruction was the primary means of materials and manufacturing teaching on Loughborough University's industrial design programme during the mid 1980s (Norman et al., 1988). However, by the early 1990s, class sizes had increased considerably, to 120 students per year group, making a top-down approach

1. A brief review of industrial design degree programmes offered at universities in Turkey (the author's current residence) and the United Kingdom (the author's previous residence) was undertaken. Outsourcing of materials teaching occurs at some of the most well-regarded institutions, including Mimar Sinan Fine Arts University and Anadolu University (Turkey); and Loughborough University and Northumbria University (UK).

unfeasible given no increase in staffing. As a result, bottom-up approaches were adopted, with students expected to apply their knowledge in other courses, principally the design practice and studio projects at the core of the Loughborough curriculum. However, there can be justified concerns about how easily students can apply their learning to product design projects. It is worth adding that in the current era of information technology, a return to top-down approaches might be contemplated by utilizing materials databases such as the Cambridge Engineering Selector, whereby individual project-based materials advice once given by a tutor can be partially replaced by student-database interactions.

Outsourced Versus In-House Teaching

It is not uncommon to find the responsibility for materials and manufacturing education resting outside of a host industrial design department (1). A reliance on outsourcing arises for several reasons. The most fundamental is access to appropriate expertise: many educators in industrial design have specialized in topics other than materials and manufacturing, leaving a necessity to call on external experts from engineering and materials departments (Norman, 1999). Other reasons include the centralization and modularisation of shared courses across degree programmes from different departments. As with bottom-up teaching, the most serious drawback of outsourcing can be a separation of the subject of materials and manufacturing from the context of designing products, thereby marginalizing the impact of course content and undermining the engagement of students.

EDUCATIONAL INITIATIVES

In reviewing the literature that connects the materials domain to industrial design practice and education, four main areas of attention became apparent. These are argued in the following sections to translate to four educational initiatives capable of invigorating materials and manufacturing teaching on industrial design degree programmes, by focusing on subject relevance, contemporary perspectives and critical thinking.

Echo Professional Practices

The Myerson report (1991) identified various sources through which the curricula and content of degree programmes are updated: lecturers' personal experience, input from external examiners, advisory boards, and feedback from graduates and designers employed as tutors. However, direct conduits from professional practice were notably absent, as were results from academic research intended to uncover and communicate professional practices.

For the industrial design student's experience in materials and manufacturing to be at its most relevant and enriching, it is considered vital that a good correspondence is made between degree course content and contemporary professional practices. Accordingly, it can be advisable to reflect within course content the range of subjects covered by professionals, whilst a framework by which industrial designers make materials and manufacturing decisions can be constructed and used as an instructional tool.

Range of Subjects

Fulton (1992) gives a useful synopsis of the responsibilities industrial designers 'do not have' towards materials and manufacturing. He states that industrial designers are not technologists, in that they do not focus their efforts toward the development of new materials or new processing technology. Nor are they scientists, because their goal is not the understanding of how properties of materials are a function of their composition and structure. Rather, designers are 'consumers of materials', concerned with selecting materials that fit to the utilitarian and expressive qualities desired in a product. Fulton's observations imply that technological or scientific understanding of materials is not 'essential' to industrial design practice. Nevertheless, the content of materials and manufacturing content on industrial design courses has historically been influenced strongly by materials engineering and materials science. The Myerson report (1991) confirmed that such content was commonplace amongst UK industrial design programmes in the early 1990s. Regrettably, no similar review has been conducted since then to reveal any general shifts in emphasis.

One of the hardest decisions facing educators is to decide which subjects should be included or omitted in a course outline. **Table 1** contains the findings of the Myerson report, combined with materials and manufacturing content taught during the author's undergraduate industrial design education at Loughborough University (1992-1995). The content highlighted in *italic* is considered to be heavily engineering and materials science based. It would be too simplistic, however, to assert that the highlighted content should be the lowest priority to teach. For example, engineers have high levels of conceptual understanding about the application of materials and manufacturing processes precisely because of their familiarity with the content highlighted in italic. Nonetheless, it is noticeable that the table itself omits content concerning the aesthetics, meanings and emotional responses to materials, each of which have become more deeply understood since the early 2000s. Thus a reasonable view is to consider 'materials experience', as a core concern for industrial design, to be a prerequisite. The remaining course load can then be selected from amongst the content in **Table 1**, alongside other missing topics including rapid prototyping / manufacture and materials and sustainability.

Framework for Decision Making

Subject Area	Content
Materials	Families; physical properties; <i>molecular bonding; morphology; strength; laboratory testing/failure modes</i> ; selection; <i>discovery/history</i>
Processes	Metal processing (methods, applications and design constraints); polymer processing (methods, applications and design constraints); other processes; finishing processes; joining, fastening and fabrication
Manufacturing	<i>Tools and methods used in design for manufacture and assembly (DFMA); planning; costing; tooling design</i>
Workshop practice	Safety; hand and power tool operation; joining and forming; model-making; CNC machining; detail and assembly drawings
Computing	Computer-aided design and manufacture (CAD/CAM)

Table 1. Materials and manufacturing content on UK industrial design courses in the 1990s.

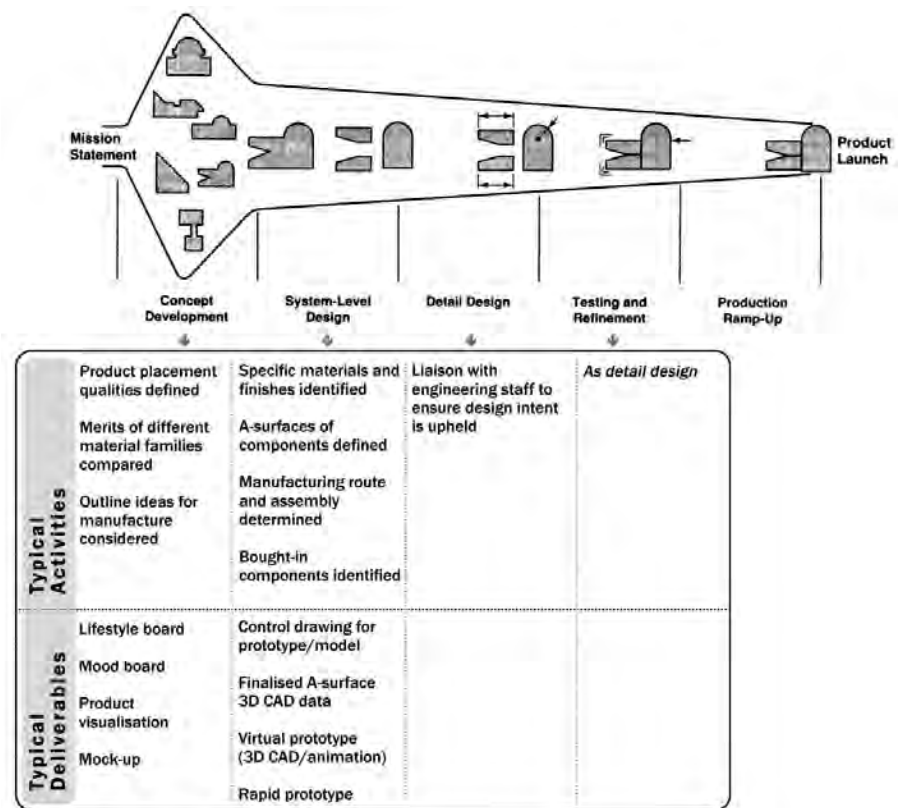


Figure 1. Phase-aligned activities and deliverables associated with industrial design materials and manufacturing selection (upper graphic © McGraw Hill).

The influence of different project stakeholders on materials and manufacturing decisions has recently been exposed, e.g. influences from clients, users, manufacturers / material vendors, and designers themselves (Pedgley, 2009). However, academic literature contains relatively little evidence concerning how industrial designers manage their involvement with materials and manufacturing throughout a design project, and the activities and deliverables involved. To this end, a re-analysis of sections of the author's doctoral interview data was undertaken, involving nine designers working at manufacturing companies, design consultancies and as freelancers. The analysis was directed by the questions, 'what activities and deliverables do industrial designers complete, and in what order, in selecting a product material and manufacturing route?'. It should be noted that the data originates from the late 1990s, when software and Internet sources were far less developed than now. More recent research by Karana et al. (2008) and van Kesteren (2008) shows that product designers use the Internet extensively to source materials information, however, strikingly, they still rarely use IT to assist in their 'materials selection' activities.

Figure 1 presents the results, tied to phases of new product development (NPD) described by Ulrich and Eppinger (1995). A distinct narrowing of materials and manufacturing choices is detectable as NPD phases are concluded. Detailed design for manufacture is carried out only in exceptional cases: when the technical acuity of the designer is sufficient and when there are no design engineers better placed to perform the work. Thus in general cases, handover to engineering colleagues occurs during the system-level design phase, whilst the communications that continue afterwards are to ensure continuity of design intent. The 'typical deliverables' are modelling media that industrial designers use to simulate

and communicate their proposals for product materials and manufacturing. These deliverables, along with the indicated activities, can be contemplated as exercises for materials and design education. The interviews also revealed that computer-based technical simulation and analysis of product designs (e.g. finite element, mould flow), which are typically made within the detail design phase, are not industrial design responsibilities.

Develop Understanding of 'Materials Experience'

The selection of materials for new products is performed not only on the basis of technical benefits but also for the purpose of gratifying users' senses and conjuring particular associations and meanings. Accordingly, we may divide these as 'technical uses' and 'expressive uses' of materials, although the division is not mutually exclusive. With such a division, the implication is that designers are required to have not only 'technical materials judgement' (regarding material properties as a means to obtain product utility) but also 'expressive materials judgement' (regarding material properties as a means to affect people's perceptions and associations). This dual perspective is necessary so that both product 'functionality' (i.e. its utility, performance in use) and supra-functionality' (i.e. its attributes that transcend -or are additional to- utility) can be successfully attended to in a product design (McDonagh-Philp and Lebbon, 2000). Increasingly it is the case that accomplished product functionality is taken for granted and that other aspects of products, gathered under the heading of supra-functionality, drive people's product evaluation and purchasing behaviour.

Methods for materials selection based on expressive uses are significantly underdeveloped compared with those for technical uses. Karana et al. (2008) completed a review into the various considerations that must be taken for effective materials selection in product design. Their results -taken mostly from an analysis of engineering texts, where materials selection is studied at greatest depth- showed expressive judgement to be almost entirely neglected. The widely acknowledged first authors to introduce expressive judgement to a mainstream textbook on materials selection are Ashby and Johnson (2002). Since then, Karana and van Kesteren (2006) have contributed significantly to the field by developing theory and tools for expressive-based materials selection and to mediate a consensus between stakeholders' ambitions for material interactions and experiences. These tools, in the form of either software or physical prompts, are at an early stage of development and not yet ready for integration into mainstream design education; however, their deployment in trials and experimental courses has been successful.

A common baseline for expressive-based selection tools is the sensorial information emanated from a material: how it may be measured, its effects on people and products, and its integration into design advisory systems. Reference to 'intangible' qualities -largely referring to the meanings or descriptions that people attribute to materials- is also a common point. The combination of functional and intangible aspects is what Karana and van Kesteren (2006) refer to as the total 'materials experience' that can be gained from a product. Materials experience emphasizes that the materials of a product communicate certain messages to users, or evoke certain associations in users' minds, and can be deconstructed into the planes of experience put forward by Desmet and Hekkert (2007): aesthetic experience, experience of meaning, and emotional experience. Similarly, Ashby and Johnson (2003) refer to materials having 'personality attributes'

linked to aesthetics, associations and perceptions. Questions may be asked of a material such as: 'for this product, does it give a good visual impression?'; 'does it convey an appropriate sense of quality?' or 'does its surface texture feel right?'.

The factors influencing materials experience identified by Karana (2009) seem at first too many, too much a mixture of relational and non-relational, and too devoid of pattern, such that considerable uncertainty is left in the mind as to whether we can confidently build theory and decision-making aids. To deal with these criticisms, Karana avoids setting rules for materials selection. Instead, her 'meanings of materials' software tool is promoted as an inspiration/creativity enabler, presenting people's varied views of material-product relationships, and leaving the designer to decide how to use the database and which information should be used to influence a developing design idea. Karana acknowledges that 'selection by similarity' (Ashby and Johnson, 2002), and its dependence on heuristics, is one of the ways in which designers can cut through the complexity of factors.

Embrace Complementary Languages to Teach Material Properties

If design students are to develop both technical and expressive judgement to support their materials decisions, it is important that they possess the necessary language to communicate decisions of a technical or expressive nature. Different languages of materials reflect different ways that people know about materials.

Scientists and engineers have developed a 'technical' language of materials, which is numerically expressed, shared and unambiguously understood by the engineering community. Accordingly, notes Manzini (1986, 53), "...to an engineer, a material is known when its properties are ... codified in a numerical form". Contrast this with the materials language of craftspeople. They shape materials into bespoke objects and have, through personal experience, developed know-how to advantageously and efficiently manipulate a given material into a desired three-dimensional form (Bunnell, 2000; McLundie, 2001; Scali et al., 2002; Shillito et al., 2004). Craftspeople mostly use a 'non-technical' (descriptive / adjectival) language of materials based on their practical experience of working with materials. For example, Lawson (1990, 38) mentions different languages for wood: "...architects are used to handling timber at a different scale and in a different context [than a furniture maker] and thus have already developed a 'timber language' with a distinctly architectural accent".

Technical languages of materials have dominated materials selection textbooks and software tools (e.g. Cambridge Engineering Selector (CES), CRC-Elsevier Materials Selector, Plascams, Boothroyd Dewhurst), presenting material properties and manufacturing information as tabulated data in handbooks and catalogues. The dominance of technical languages is unsurprising, given that the majority of materials selection resources are targeted to engineers who seek a match between material properties and product performance. It is worth noting that CES has found advocates on technically oriented industrial design degree courses. The successful integration of CES into these courses is possibly because material properties are communicated through charts (rather than tabulated data), which would be more compatible with industrial designers' visually oriented modelling methods (Layton, 1993; Norman, 1998; Vincenti, 1990). Non-technical languages of materials are usually communicated through

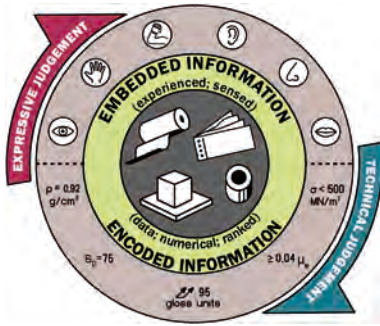


Figure 2. Material languages based on information embedded in, and encoded from, material samples.

images or verbal descriptions and have not been studied or collated to any degree of coherence or universality.

The language of materials and manufacturing appropriate to industrial design can be regarded as a combination crafts (non-technical) engineering (technical). Engineering languages are still regarded as important because industrial designers must engage in effective communications with their engineering colleagues during NPD and take command of some technical decisions. To this end, **Figure 2** proposes a schematic of material languages for industrial design, divided between 'information embedded in a material' (experienced through our senses)(2) and 'information encoded about a material' (comprehended through numerical data). Figure 2 reinforces that languages based on embedded and encoded information are complementary and point to the same origins. Furthermore, they have a tendency to support expressive and technical judgements respectively. It is important at this point not to overlook the role of personal contexts or values in shaping designers' (or other stakeholders') materials judgements. For example, how do they feel about the origin of a material or the energy that goes into its processing? Are they driven by a truth to materials maxim? Material values are 'experienced in the mind' rather than through embedded or encoded information.

Following from **Figure 2**, in the author's opinion, it is a misconception and mistake to further the notion that there are 'sensorial properties' and 'technical properties' of materials. Instead, it is preferable to acknowledge that materials simply have 'innate properties'. These properties may be inherent to the 'raw' material or they may arise from manufacturing processes, supplementary finishes, and so forth. Whether they are sensorial or technical is actually a label or description (meaning) that we, as designers or users, attribute to a material. Such attributions are a reflection of how we experience materials, or our subjective regard for how materials can be put to good uses in a product. They are also a convenience of classification rather than an actual point of difference. For example, 'stiff' (a kinaesthetic sensorial description) is equivalent to a high value of Young's modulus (a technical description); 'non-slip' (a tactual sensorial description) is equivalent to a high coefficient of friction (a technical description). Some material properties are used mostly, maybe even exclusively, to achieve utility within a product, and may not even emanate any sensorial information (e.g. electrical conductivity, flammability). Likewise, some properties have less dominant utilitarian application but more important expressive uses (e.g. reflectivity). Some properties have obvious dual uses: translucency in a pen may notionally be for utilitarian use (seeing the ink level) but can contribute to giving the pen an attractive, frosted, curious appearance.

Teach through Physical Material and Product Samples

How can we teach materials experience in its broad sense, and also respond to the lack of exemplars for developing expressive judgement for materials selection? A useful starting point can be to adopt, as much as possible, teaching based around physical material and product samples. This way, students can themselves partake in a materials experience first-hand, rather than have their understanding limited to representations in literature or online. One of the major strengths of sample libraries is that they help designers to better comprehend material properties through direct sensorial exposure. For example, materials can be visually appraised in different lighting conditions, at different viewing angles, smelt, surface

2. If we consider that a substantial portion of a craftsman's material expertise is gained through sensorial information, by 'working with materials', we must also consider the relevance of crafts epistemology to industrial design. That is, the relevance not only of direct manipulation of materials (considered shortly) but also of tacit knowing and know-how (outside the scope of this present article). For instance, if we consider that not all properties of music can be expressed through notation, then it is plausible that not all properties of materials can be encoded or verbalized and instead must be directly experienced.

qualities and textures can be felt, the weight of the material can be experienced, and its rigidity evaluated. Such vocational learning is very normal for designers across professions, who make use of acquaintances with existing creations to help innovate (Middleton, 2003). They gather project-specific information on a need-to-know basis, by reading and writing knowledge that resides within manmade creations: "...essentially, we can say that designerly ways of knowing rest on the manipulation of non-verbal codes... [within manmade things]" (Cross, 2006, 10).

Indeed, such activities are a basic human characteristic. A child's early experiences of the material world are through play, where he/she develops personal knowledge by handling, constructing and deconstructing objects, independent of verbal communications (Eggleston, 1998). Learning through sensorial exploration is a method that is encouraged in very young children. For example, in the Montessori preschool system, children are encouraged to explore the world of objects and develop knowledge by the discrimination of sensorial qualities of materials including smell, weight, colour, texture, sound and temperature (Morrison, 2007). A hands-on approach to materials education is therefore posited as a means to help designers develop an affinity for the suitability of materials and their limits of application. Furthermore, by disassembling products, technically oriented knowledge such as joining methods and internal structures (e.g. wall thickness, bosses, webbing) can be gained.

Learning through handling and evaluating material samples is a well established approach to extending one's materials knowledge, as evidenced by the material libraries maintained by, for example, Material ConneXion (Bangkok, Cologne, Daegu, Milan, New York), MADE Materials Resource Centre (London), Materia Inspiration Centre (Naarden), Material Lab (London), and IDEO Tech Box (Palo Alto). However, the compilation of such collections is expensive – especially for educational institutions. Furthermore, recent research has shown that despite the high value that designers in industry place on material samples, they rarely themselves consult commercial sample libraries (van Kesteren, 2008). Instead, they prefer to build personal collections as a source for reference and inspiration.

Learning through Making

The view that materials and manufacturing aptitude should be developed with at least partial emphasis on 'learning through making' is given credence from research findings that show industrial designers seek much of their materials knowledge augmentation through creating mock-ups and prototypes (van Kesteren, 2008; Pedgley, 1999). Designers create physical models in end materials to test out the suitability of new or newly applied materials to a developing product design. Sometimes this is the only way to assess whether a material can meet design requirements, or to explore the as-yet-unknown product possibilities of new materials.

Instil Systematic Material Selection Methods

The general aim of a selection method is to 'screen' (eliminate) those materials that are not viable for use in a product proposal, thereby leaving a shortlist of viable materials for further review. Usually this results in a convergence towards a particular material and process combination. Thus an educational objective for materials selection is to instil in students the confidence and expertise to progress from an initial point (i.e. product ideas with no appreciable consideration of materials and manufacturing)

to an advanced point (i.e. a final decision that a product component will be manufactured from material x , supplementary finish y and shaping process z). This may be either a quick or protracted decision, based on particular circumstances and the product being designed. Ashby et al. (2004), Fischmeister (1989) and van Kesteren (2008) each identify similar steps for achieving a material match to design requirements, summarised below.

- i. Determine material properties (a requirements profile) most critical for the design task.
- ii. Screen materials that cannot deliver the necessary properties, leaving a new subset.
- iii. Rank subset materials using weighted criteria, leaving a preferred shortlist.
- iv. Test shortlisted materials through practical materials exploration.
- v. Search for further information on shortlisted materials, concerning applications, history and weaknesses.

CASE STUDY

To put the educational initiatives into practice, a modest action research project was undertaken. The aim was to evoke positive changes to the Bachelor of Industrial Design (BID) compulsory course 'ID236 Manufacturing Materials', taught in the Department of Industrial Design, Middle East Technical University (METU), Ankara. The BID programme at METU is one of the oldest and most prestigious in Turkey, and fits to the mould of a traditional industrial design curriculum that does not seek an elevated mechanical and electronics prototyping capability in students. As with all the founding industrial design programmes in Turkey, its origins can be traced to architecture (Bayazit, 2009).

The official language of instruction at METU is English. ID236 is given in the second year of instruction (of four years total) and typically has a capacity of 40 students. Delivery is through weekly sessions lasting up to three hours, across a 15-week semester. Student contact time is therefore nominally 45 hours for the entire course. The course grade is calculated from a combination of assessed components: final exam (35%), midterm exam (25%), project (15%), field trip report (15%) and attendance (10%).

Prior to enrolling onto ID236, students take other materials-related courses 'ID290 Elementary Workshop Practice and Computer Literacy in Design' and 'ME212 Principles of Production Engineering', the latter offered by the Department of Mechanical Engineering. In ID290, students gain hands-on experience of product fabrication in woods, metals, plastics, ceramics and model-making materials, thereby fulfilling the identified need to learn about materials through making. In ME212, students are lectured on metals and metal processing from an engineering perspective, and have an introduction to machine shop practices and automated manufacturing. As the terminal input for materials education on METU's BID programme, the content and delivery of ID236 has critical impact on the capability of students to take materials and manufacturing decisions in their subsequent design projects.

Up until the 2006-07 academic year, ID236 had been structured around industry visits, insightful anecdotes and personal experiences, but without the benefit of a developed lecture series or accompanying handouts for

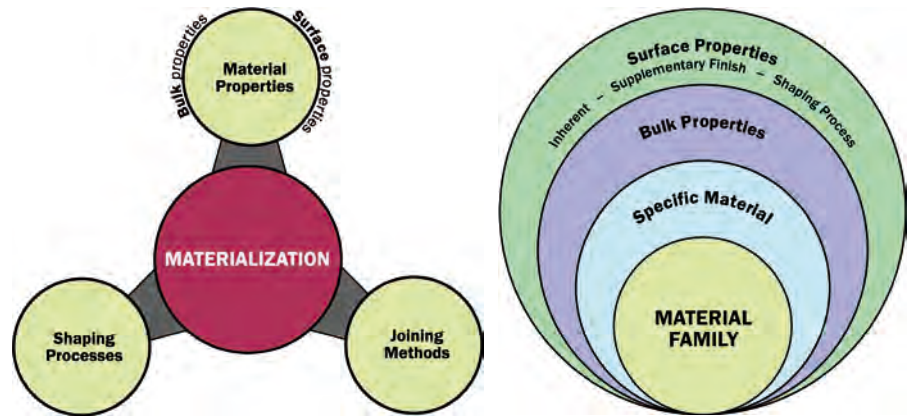
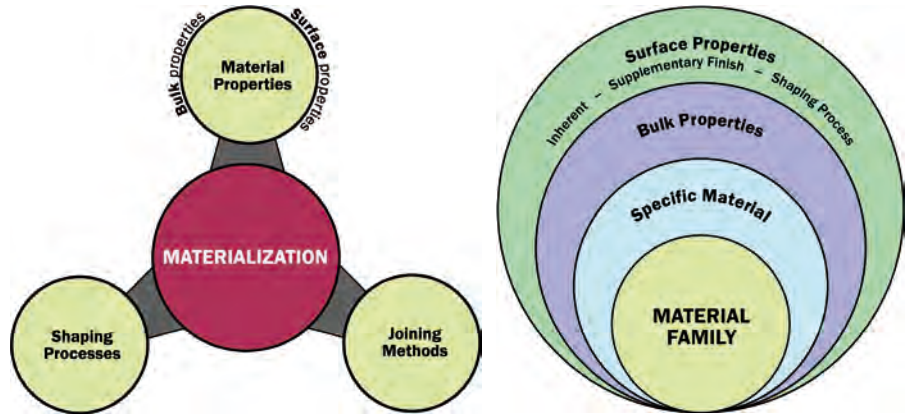


Figure 3. Tri-nodal approach to teaching materials and manufacturing.

Figure 4. Onionskin approach underlines hierarchy of material properties.



students. For the 2006-2007 academic year, following the retirement of the responsible staff member, a first round of changes to ID236 were initiated, involving the creation of a formal lecture series. Starting from the 2007-2008 academic year, the author was appointed to instigate a radical overhaul of ID236 content and delivery to ensure its relevance to industrial design education. The general approach taken was action research, involving a critique, evaluation and adjustment of each consecutive year's teaching. The research questions posed were the same as RQ1 and RQ2 posed in this article.

Implementation of the Educational Initiatives

The overhaul to ID236 was structured around implementation of the four educational initiatives. The course continued to be hosted by the Department of Industrial Design (i.e. not outsourced), but was now staffed by graduates of industrial design. In the revised course handout, the overall aim of the course was described as below.

"ID236 aims to establish and develop an awareness and capability for selecting materials and manufacturing processes appropriate to industrial design. Subjects include selection methodology, properties of materials (including plastics, metals, woods, composites, glass, ceramics), shaping processes, supplementary finishing processes, and component joining methods. The idea of materials experience and different languages of material properties are introduced. An industry field trip to manufacturers is organised."

The course handout also set out the new educational objectives for ID236.

"On completion of the course, students should have:

- gained awareness of the importance and scope of materials and manufacturing within the profession of industrial design;
- become familiar with the main influences driving industrial designers' choices of materials and manufacturing routes;
- acquired a broad knowledge of materials, forming, finishing and joining methods specified by industrial designers;
- developed skill in materialising product ideas."

A tri-nodal approach to teaching was adopted for ID236 (Figure 3). Materials selection (materialization) was at the core, with the three vertices occupied by the conjoined subjects of material properties,

shaping processes and joining methods. The intention with this approach was to emphasize to students that designers generally travel to and from the vertices of the triangle, gradually refining their materials and manufacturing choices until eventually reaching a final decision. Knowledge was required for each vertex, as well as for the decision-making processes involved in materialization. The course was therefore structured as a series of lectures focusing each week on a different material family. Then, later, lectures and workshops on materials selection for product design were provided, giving students opportunity to put their new materials knowledge into practice.

An 'onionskin' approach was adopted for teaching a hierarchy of material properties. The approach is visualized in **Figure 4**, and can be elaborated thus:

Bulk properties.: These are the properties of a material that permeate throughout its structure (e.g. density, strength, rigidity, elasticity).

Surface properties: These are properties of material surfaces that have a significant effect on people's interactions with materials, especially regarding appearance and perception (e.g. colour, reflectivity, texture, relief, softness, decoration, graphics). Surface

Initiative	Response
Echo Professional Practices	Materials were introduced mostly through their practical application to industrial/product design (i.e. top-down approach), thereby helping to reinforce the influence of stakeholders on selection activities. Materials science topics were purged from the curriculum.
Develop Understanding of 'Materials Experience'	Since industrial designers must be concerned with product utility and performance, the <i>primary emphasis</i> was still <i>technical uses</i> of materials. The <i>secondary emphasis</i> was on the evaluation of materials for <i>expressive uses</i> , mentioning notable or remarkable sensorial properties of materials that give a special appeal or attractiveness beyond their utilitarian uses. Material properties – communicated sensorially or numerically coded – were reviewed in a dedicated lecture and then revisited in detail within specialist material family lectures. An 'onionskin' approach was adopted for teaching a hierarchy of materials properties.
Teach Through Physical Material and Product Samples	Development of sensorial judgement was bolstered through a material and product samples library; the samples were distributed to students during the lectures so as to gain first-hand material experiences. The industry field trip was maintained as a valuable means for students to gain additional first-hand material and manufacturing experiences.
Instil Systematic Material Selection Methods	A three-layered approach to material selection was emphasized. Layer 1 involved understanding the product sector, layer 2 involved considerations of stakeholder influences, and layer 3 involved materialization of product ideas on a component basis.

Table 2. Incorporation of educational initiatives into ID236.

properties may (i) be inherent (i.e. come directly from the material), (ii) be present because a supplementary finish has been applied to alter or mask the material, or (iii) arise as a result of the shaping process used to create a part.

The ways in which each of the four educational initiatives was incorporated into the renewal of ID236 are summarised in **Table 2**.

Course Evaluation Methodology

RQ2 was probed through pre-course and post-course questionnaires completed by ID236 students in the academic years 2007-08 (n=28/41) and 2008-09 (n=33/39). The questionnaires had four short Likert-scale sections and one free-text section. Four-position Likert scales were preferred, deliberately avoiding a fifth (neutral) position so as to encourage students to give answers that were clearly positive or negative. At the data analysis stage, the Likert scale responses were converted to metrics, as follows.

- Section 1 asked students to indicate whether they 'agree strongly' (+2.0), 'tend to agree' (+1.0), 'tend to disagree' (-1.0) or 'disagree strongly' (-2.0) about the importance, enjoyment, technical nature and aesthetic nature of materials and manufacturing.
- Section 2 asked students to rate their plastics, metals, wood, glass, ceramics and composites knowledge as either 'good' (+2.0), 'quite good' (+1.0), 'quite poor' (-1.0) or 'poor' (-2.0).
- Section 3 asked students to rate their skills in selecting materials, manufacturing processes, finishing processes and joining methods as either 'good' (+2.0), 'quite good' (+1.0), 'quite poor' (-1.0) or 'poor' (-2.0).
- Section 4 (post-) asked students to state the perceived improvement in their knowledge, having completed ID236, for plastics, metals, wood, glass, ceramics and composites, using the scale 'improved significantly' (2.0), 'improved slightly' (1.0) and 'no improvement' (0.0).
- Section 5 was a free text area for students to suggest course topics (pre-) and express positive/negative comments about ID236 (post-).

Data were processed as combined/mean values for the whole academic year group. It is acknowledged that the primary weakness of the adopted evaluation approach is the reliance on student self-assessment. Therefore an additional analysis was made to test the general validity of students' responses. The mean grades for section 2 (material family knowledge) and section 3 (selection skills) of the post-questionnaire were calculated for each student individually and plotted against overall course grades. The results are presented later, alongside those of section 4 of the questionnaire. The anticipation was to see a positive correlation between students' self-assessments and their awarded course grade.

Questionnaire Section 1: Impressions about Materials and Manufacturing

Combining both year groups, students agreed strongly that the subject was important (+1.9), whereas they tended to agree that the subject was enjoyable (+1.4), technical (+1.3) and aesthetic (+1.0). Only very small differences in opinion existed between the pre- and post-questionnaire results, indicating that completion of ID236 did not alter students'

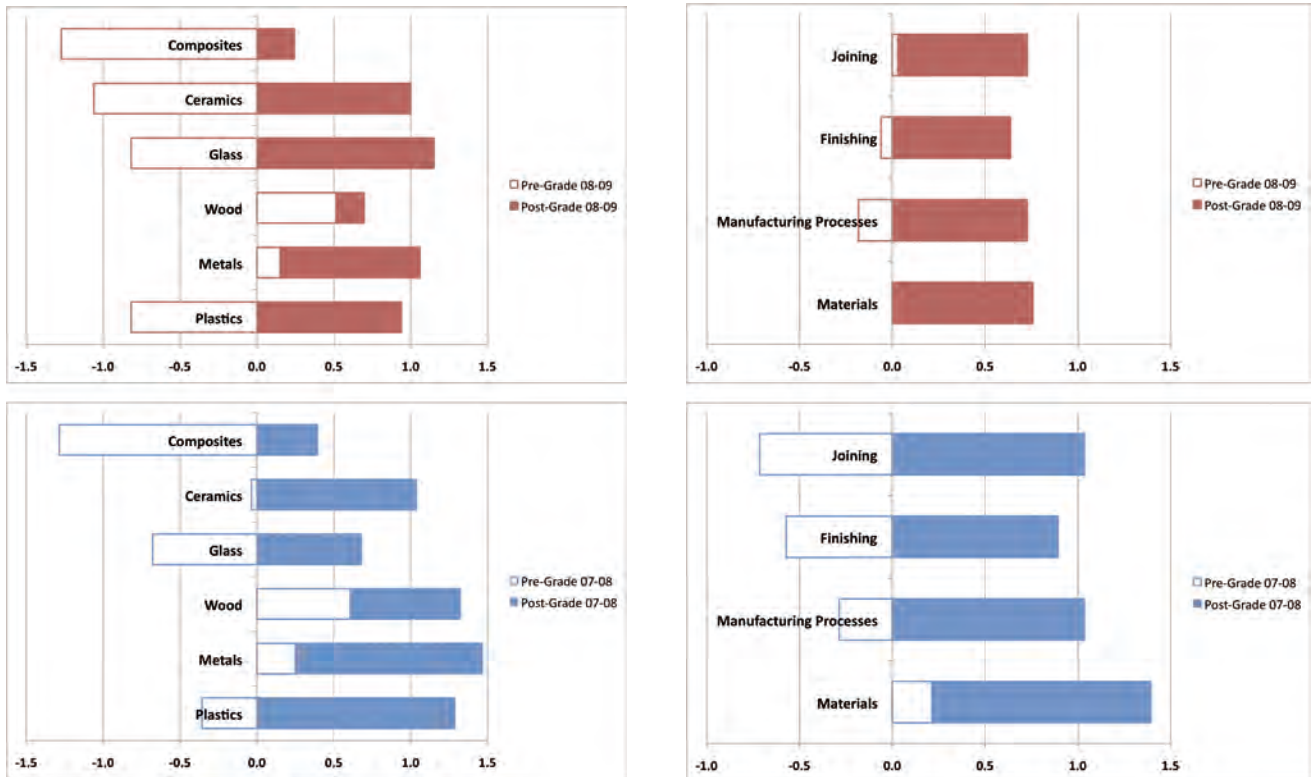


Figure 5. ID236 – material family knowledge (top 2008-09, bottom 2007-08).

Figure 6. ID236 – selection skills (top 2008-09, bottom 2007-08).

impressions about materials and manufacturing as a subject, and that teaching of the aesthetic attributes of materials needs further attention.

Questionnaire Section 2: Material Family Knowledge

The results of section 2 of the questionnaire are visualized in **Figure 5**. Knowledge for all material families prior to ID236 was graded between quite poor and quite good, except for knowledge of composites (and ceramics, 08-09 only), which was graded the lowest: between very poor and quite poor. On completion of ID236, the material families for which students reported strongest knowledge were glass and metals (08-09) and ceramics, wood, metals and plastic (07-08), with each material family upgraded to between quite good and good. The results suggest that teaching was most effective for the aforementioned material families. In contrast, for both year groups, the material family for which students reported the weakest knowledge on completion was composites, although it was still upgraded to between quite poor and quite good. Attention should therefore be paid to improving the teaching of composites.

Questionnaire Section 3: Selection Skills

The results of section 3 of the questionnaire are visualized in **Figure 6**. Skills in all selection activities prior to ID236 were graded between 'quite poor' and 'quite good'. On completion of ID236, students reported grades within the same range, except for materials selection in 07-08, which was upgraded to between quite good and good. Despite all selection activities receiving higher post-grades than pre-grades, the results in Figure 6 show that overall teaching of selection skills must be improved if a step-change in student attainment is to be achieved.

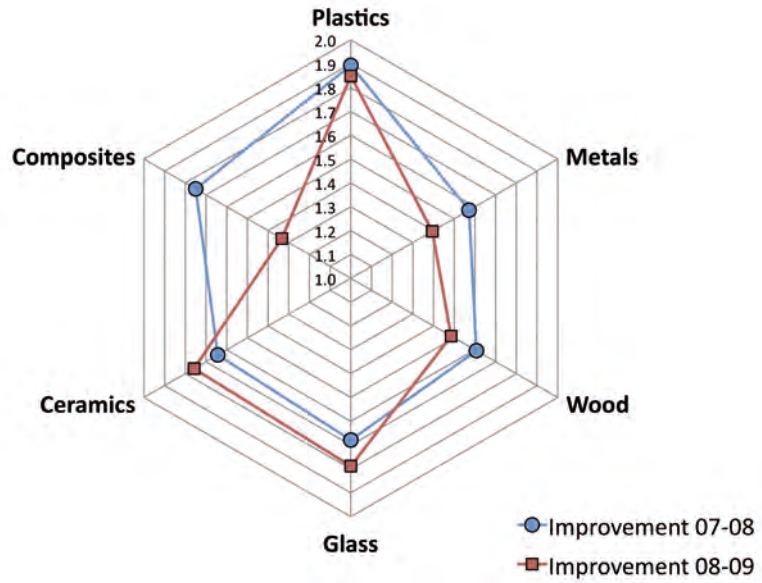


Figure 7. ID236 – perceived improvement in material family knowledge.

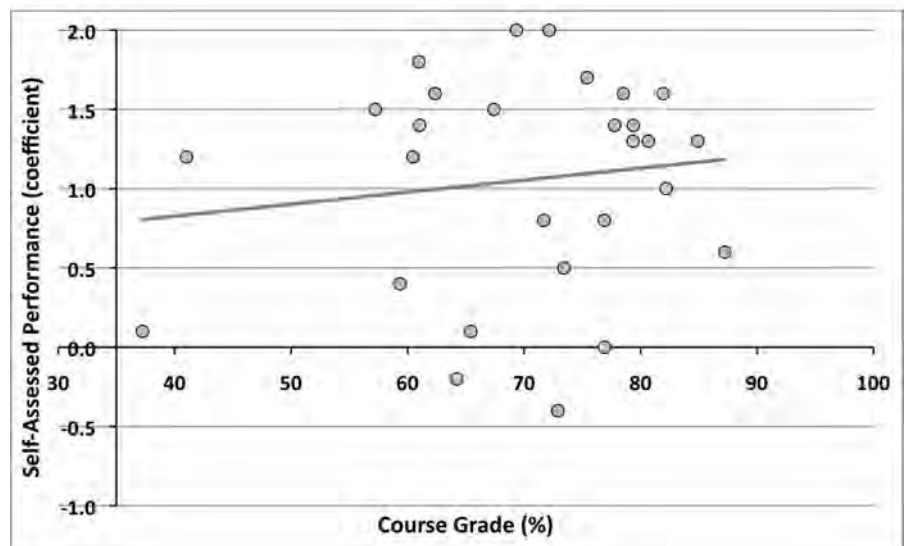
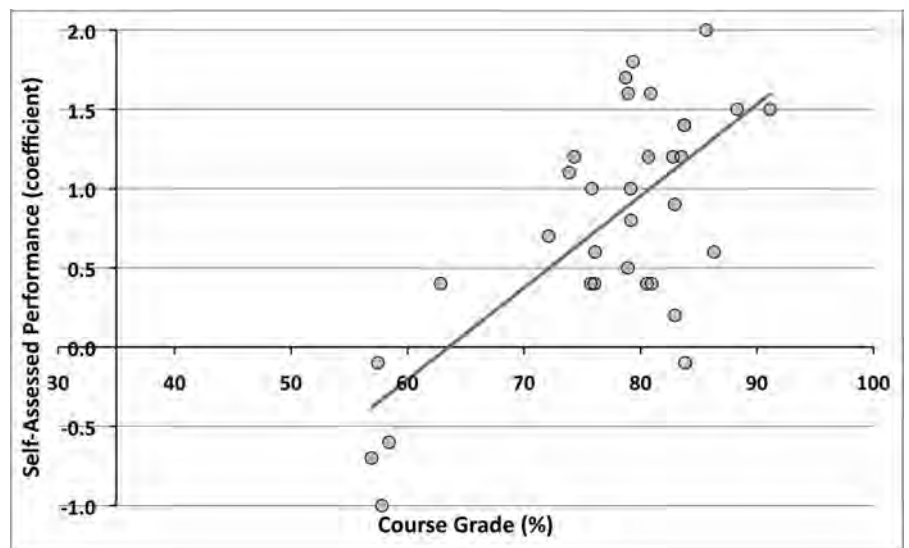


Figure 8. ID236 – self-assessed performance and course grade (top 2008-09, bottom 2007-08).

Questionnaire Section 4: Perceived Improvement

The results of section 4 of the questionnaire are visualized in **Figure 7**. The grades show perceived improvements for all material families, the majority being close to 'improved significantly'. The perceptually most improved was plastics (07-08 and 08-09) and the perceptually least improved was metals (07-08) and composites (08-09). These findings echo principal findings of section 2 of the questionnaire: that plastics were probably taught well, but composites (and here, metals) were probably taught less well.

It was mentioned in the course evaluation methodology that doubts could be expressed over the validity of student self-reports. **Figure 8** contains data intended to alleviate those doubts. It shows the combined calculated mean value from section 2 (material family knowledge) and 3 (selection skills) of each student's post-course questionnaire, plotted against that student's overall grade given by the course tutors. A positive correlation could be detected between students' self-assessments and their awarded course grade: for 0708 the correlation was evident but weak, however for 0809 the correlation was far stronger. Those students who gave low self-assessments of performance on average also received low course grades, whereas those who gave high self-assessments on average received high course grades. These findings render the student self-reports a valid source of data.

Questionnaire Section 5: Positive and Negative Aspects

The results of section 5 of the post-course questionnaire (for 0708 and 0809 combined) are visualized in **Figure 9**. Using online word cloud analysis (Wordle, 2010), it was possible to visualize the most frequently mentioned issues in students' comments about their positive and negative aspects of ID236. In preparation for the analysis, similar themed words were reduced to a single word (e.g. images, visuals, slides = presentations; lots, amount, many = overloaded). The four most frequently cited positive experiences, in rank order, were: fieldtrip, learning, presentations and samples. This indicates a successful balance in the course delivery between lecture-based



Figure 9. ID236 – students' positive (top) and negative (bottom) experiences.

and experiential learning. Negative experiences, in rank order, were: overloaded, brisk, non-detailed and memorizing. This indicates that whilst the course delivery is appreciated, the topic variety may currently be too ambitious and detract from a deeper understanding of underlying issues.

CONCLUSIONS

The article has used literature and fieldwork to argue for a re-evaluation of content and delivery of materials and manufacturing training for industrial design undergraduates. Two research questions were posed to guide the reported work.

In response to RQ1, the findings of the research led to the recommendation of four educational initiatives that can be implemented to invigorate existing courses that are currently biased towards engineering approaches, or otherwise insufficiently directed to the needs of industrial design students. The four initiatives are: echo professional practices; develop understanding of 'materials experience'; teach through physical product and material samples; and instil systematic material selection methods. It is suggested that these initiatives can help deliver materials and manufacturing teaching to students in an engaging and enthusing manner.

RQ2 concerned whether or not a positive student experience can be obtained from a materials and manufacturing course amended to the recommendations from RQ1. This question was investigated through the development, over two academic years, of the compulsory ID236 Manufacturing Materials undergraduate course offered by the Department of Industrial Design, Middle East Technical University. The findings conclusively showed that the revised course delivered a strongly positive student experience but with scope for improvements. ID236 will therefore continue to be iteratively improved, incorporating some or all of the following points arising as a result of this article.

- Address students' negative comments: 'overloaded' (reduce breadth of content), 'brisk' (devote more time to fewer topics), 'memorizing' (in preference to written examinations, formally teach, through practical exercises, activities and deliverables cited in Figure 1), and 'non-detailed' (increase depth of content).
- Divide the course across two semesters to allow better distribution and management of content.
- Give formal teaching input to selection tools and methods for sensorial-expressive uses of materials.
- Evaluate course effectiveness by examining whether students' ID236 knowledge and skills are successfully implemented in year 3 and 4 studio design projects.

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Anahtar Sözcükler: malzeme; endüstri ürünleri tasarımı; eğitim; ders müfredatı.

ENDÜSTRİYEL TASARIM MALZEME VE ÜRETİMİ EĞİTİMİNİ CANLANDIRMAK

Malzeme ve küçük üretimin endüstri ürünleri tasarımcıları için yaşamsal önemde olduğunu söylemek gerekir, çünkü malzemenin işlenmesi yoluyla sanal ürünler fiziksel gerçekliğe kavuşurlar. Tarihsel açıdan bakıldığında malzeme ve üretim eğitiminin mühendislik yaklaşımlarının egemenliğinde olduğu görülür; ne yazık ki bu yaklaşımlar da endüstri tasarımcılarının insan-merkezli kaygılarına uzak, aşırı teknoloji-odaklı bakışlara sahiptir. Örneğin ürün işlevi-randımanı temeline seslenen malzeme seçimi ortamı kurumsallaşmıştır; oysa ürün ifadesi-kişilik temelli bir malzeme seçiminin oldukça ilkel kaldığı gözlemlenebilir. Yakınlarda ortaya çıkan bir grup yeni

araştırma endüstri amaçlı ürün üretimindeki malzeme seçimine insancıl bakışın ne olabileceğini sorguluyor. Bu araştırmalardaki ortak nokta, ürün farklılaşması, markalaşma ve diğer ticari zorunluklar gibi geniş bir beklenti yelpazesi içinde ve en az onlar kadar önemseyerek, malzemeyi kullanıcının ürünle olan estetik, anlamsal ve duygusal düzlemlerdeki deneyimini etkileyecek, biçimleyecek yolları tasarımcılar için arayıp ortaya çıkarmak. Bu yeni grup araştırmaya endüstriyel tasarım malzeme ve üretim eğitimine yeniden bakma eğilimi eşlik ediyor. Bu makale, günümüz ve geleceğin endüstriyel pratikleriyle daha rahat paralellikler kurmay amaçlayan bir öğretimsel değişim örneğini sunmakta. Araştırma bulguları yayın taraması, tasarımcılarla yapılan söyleşi belgeleri ve ODTÜ Endüstri Ürünleri Bölümü'nde yapılan malzeme ve üretim eğitimi geliştirme-değerlendirme çalışmasına dayanmakta. Endüstriyel tasarım malzeme ve üretimi eğitimi canlandırmak üzere dört ele alış öneriliyor: a. Eğitim konuları yelpazesini ve karar verme bağlamlarını mesleki pratikler açısından yeniden ele gözden geçirmek; b. malzeme deneyimi üzerine, malzemenin özellikle duyumsal ve dokunulamaz-ölçülemez nitelikleri konusunda görüş geliştirmek, malzeme özelliklerini öğretirken teknik ve teknik-olmayan dilleri aynı anda kucaklamak; c. malzeme ve ürün örneklerini eğitim kaynakları olarak kullanmak ve özellikle 'yaparak öğrenmek' stratejilerinden yararlanmak; d. sistematik malzeme seçimi yöntemlerini malzemenin 'yararacı' ve 'ifadeci' kullanımını için kalıcı hale getirmeye çalışmak.

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