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

IMPROVED METHODS FOR TEACHING PRODUCT FORM DESIGN TO ENGINEERING STUDENTS

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ABSTRACT
This paper presents the results of an ongoing experimental "Designeer" programme of teaching end-user product design to undergraduate engineering students using a hybrid approach of traditional industrial design coupled with product engineering. The programme's objectives are: 1) prepare engineering students to create credible product designs when no industrial designer is available, and 2) instil understanding and appreciation of the discipline of product design to work collaboratively with industrial designers. Topics and skills are provided in these programmes that are not ordinarily taught to undergraduate engineers, e.g., manual perspective sketching and aesthetic product form design. In teaching such unique content, a number of cognitive, perceptual, skill and application deficiencies in engineering design education were discovered. Herein described are the applied remedies, the improved methods developed, and the results that are an educational success. The improved methods are: 1) a Y-system approach using multiple support tools for realistic manual perspective sketching, and 2) a combination of manual orthographic sketching and computer aided design (CAD) for aesthetic product form development.

Keywords: Product design, engineering design, industrial design, design education, design visualization, design form-giving, concept sketching.

1 INTRODUCTION

Over the past five years the authors have developed a product design programme for undergraduate engineering students at Hongik University in Seoul, Korea. In creating the programme's courses and instruction the following educational issues were addressed:

- Engineers can work well with industrial designers if engineers are trained to understand and appreciate industrial design objectives and problems and experience its methods and applications,
- Engineers should be able to competently fill the role of product designer and execute quality product design if an industrial designer is not available,
- The aesthetic product form-giving should not be limited to the sole discipline of industrial design—engineers, properly trained, should be able to adequately execute and excel in this area as well,
- Engineers should be able to create new and innovative real-world human-centred products without being highly trained sketch artists, and
- Engineers, when educated in STEM topics and additionally instructed in design principles and skills, may be better prepared to create superior product designs as hybrid "Designeers".

This programme set out to support these issues with hands-on product design instruction to augment traditional engineering education. One of the important features of the programme is to teach engineering students how to create and utilise visual images and form-giving in their conceptual design phase. The students are taught freehand perspective sketching along with aesthetic product form-giving. This paper presents the major findings from teaching two main programme courses: 1) Design Visualisation & Simulation Methods, and 2) Form & Aesthetics for Engineering Design. It also presents reflections on causes of those findings, the remedies and improved methods developed,

and the results.

1.1 Literature and research background

Freehand manual sketching has been and still remains the major means for creating, communicating and explaining conceptual ideas for all types of designers [1-7], with the manual medium being often both paper and digital means. Likewise, CAD software has been adopted as the standard tool for most engineering design and much industrial design as well [7] [8]. In the engineering development process, three-dimensional (3D) CAD models are indispensable—not only used for the design stage, but also for the following stages such as computer-aided engineering (CAE), computer-aided manufacturing (CAM), and so on.

A great number of research papers and articles in the literature have addressed whether freehand sketching in the initial conceptual creative design stage can be supported or even replaced by CAD [4-7]. A majority of researchers and design practitioners believes that freehand sketching is still the core conceptual tool [1-4] although a few case studies show that this stage involves more verbal activities and digital work than sketching [4]. Therefore, significant research and development [5] [6] has been done in developing computer-aided sketching (CAS) tools that assist freehand sketching with digital media. CAS tools are valuable because they can aid in the smooth transition from sketches to CAD, and then to CAE, CAM, etc.

In spite of the number of related papers, it is difficult to find studies on recent teaching freehand perspective sketching or aesthetic product form design to engineering students similar to that taught to industrial designers. Close ones are primarily about the relative time spent on and sequence of the use of freehand sketching and CAD by students and/or practitioners during design projects [3] [4] [7], but are primarily about schematic, orthographic and/or axonometric delineation. Therefore, the present paper has a unique contribution in presenting first-hand experiences in teaching realistic freehand perspective sketching and aesthetic product form development to engineering students, observing the student difficulties, finding causes of difficulties, devising remedies, improving teaching methods, and concluding with statements on teaching product design to engineering students and needs for rigorous future studies.

1.2 Programme student makeup

Though the work that supports this paper was executed at Hongik University in Seoul, Korea, to primarily Korean engineering students, the programme participants included some engineering and design exchange students from Germany, France, Philippines, and several other non-Korean countries. Students were primarily junior and senior mechanical engineering students with a few from other engineering disciplines such as industrial, software and/or electrical. There were around 30-40 students in each class with a mixture of male and female students, averaging 20-25% female. Almost all the of the students had previous instruction in design thinking, innovation, design process and creativity, but initially had a generally low level of sketching ability as early testing determined. Very few had any previous instruction in industrial design or product form-giving.

2 TEACHING MANUAL PERSPECTIVE IDEA-SKETCHING

Product form development is a visual enterprise and form creators must be able to produce good, clear visual representations of their form concepts. Due to its inherent nature, expressing aesthetic product form requires visual precision and accuracy—without such, the reality of the presented form cannot be perceived properly. The original programme plan was for engineering students to develop product form concepts using primarily freehand perspective sketching. Sketching in perspective was generally new to the students since engineering education almost exclusively relies on orthographic and axonometric delineation, in contrast to industrial design and architecture where students are extensively trained and practiced in realistic perspective sketching. All students were instructed in three-view orthographic and one-, two- and three-point perspective and tested for their understanding, resulting in a roughly 90% comprehension rate for each class. However, the issue was not understanding the mathematical foundation of perspective—the problem was students being able to execute realistic manual perspective sketches of form designs. The authors' philosophy for teaching design sketching is:

- Design idea-sketching is about developing a final creative concept, and not about fancy art,
- Extensive and sophisticated manual sketching is not only usually impossible for most engineering

students, but can also be detrimental to the form-giving process with too much focus on the sketching style and quality rather than on the form design itself,

- Idea-sketching is a universal and valuable form of human externalised thinking and creative enhancement using eye-hand-brain coordination to visualise new ideas and concepts,
- Once a product idea or concept has been adequately sketched, it should then be taken to CAD for precision execution and refinement, rather than with more over-wrought additional sketching, and
- Any supporting device or method that assists in manual idea-sketching may be used.

2.1 Difficulties in perspective sketching

In the product visualisation course, the predictable student hesitation to sketch was found immediately. In addition, several rather surprising issues were also discovered in the students' work. First, most of the students had great difficulty with manual perspective sketching as shown in Figure 1 (a, b). After initially allowing only unassisted manual freehand sketching, the students were then instructed in and allowed to use assisted perspective sketching using the following devices and methods:

- Orthographic and perspective underlay grids as guides,
- Preliminary bold blocking-out of rough forms to use as underlay's,
- Straight edge rulers and curved guides, and geometric shape, circle and ellipse templates,
- Tracing paper overlays for multiple sketch iterations, and
- Photocopies of product images, partial sketches, and CAD images for over-sketching.

The students were also instructed extensively in a so-called Y-system of perspective sketching with an accompanying grid underlay shown in Figure 1 (d) that utilises only a single canonical central perspective view for all sketches. In this method students always sketched their form ideas and concepts from the same perspective viewpoint. This facilitated a sketching practice and execution with a high consistency of geometric shapes, forms and elements (e.g., cuboids and ellipses) between sketches as in Figure 1 (c).

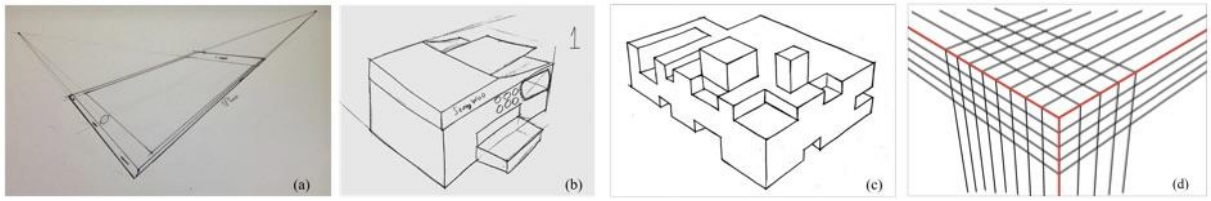

Figure 1. Wrong perspective (a, b), improvement using the Y-system (c), Y-system underlay (d)

2.2 Difficulties in perspective perception

Many of the engineering students had another surprising difficulty of "seeing" perspective, even in their later CAD modelling. The visual education of engineering students is typically limited to orthographic and axonometric drawings and pictorials, numerical dimensioning, and computational exercises such as free-body diagrams. Orthographic and axonometric CAD drawings do not represent what is seen by the human eye and are distorted from perspective reality. The student difficulty may also be due to engineers seldom making layout or production drawings manually, but relying almost exclusively on CAD for this. The authors feel this scenario appears to hinder an engineer's ability to both see and sketch in perspective reality by hindering a sense of realistic space and form. It seems almost as if the exclusive use of the visually skewed orientation of orthographic and axonometric CAD visualisation contributes to a non-realistic visual reality perception!

2.3 Difficulties in size and proportion perception

The engineering students also often had a lack of "seeing" a correct perception of actual sizes, proportions and shapes. The students were often inaccurate in their execution in both sketches and CAD models of realistic dimensions and proportions. Their early product designs were frequently unrealistic and their product features and elements often had strange shapes that were unreasonable or unattractive or both. It was also assumed that engineering students would naturally be able to apply their previously learned STEM principles to real-world product design. However, it was found that

they had difficulty in applying this knowledge to even common machines, products and tools. This may indicate a deficiency in engineering education, which often focuses on abstracted situations and seldom considers real-world design of electromechanical product systems that require a sense of layout among their elements.
Students were pushed to "see", understand and execute realistic product design and consider product internal electromechanical functionality and layout that often drives external product form. They were instructed to sketch internal electromechanical product components and layouts in schematic form with proper proportions, sizes, shapes, ergonomics and manufacturing by the following means:

- Showing cross-sections of interiors and components of a variety of actual high-tech products,
- Showing a variety of typical product components such as fans, power supplies, electronics boards, motors, cabling, displays, connectors, controls, etc.,
- Bringing actual products into the classroom and doing "design forensics" where the students take apart the products to experience their electromechanical design hands-on,
- Having students sketch orthographic cross-sections of various high-tech products and their internal electromechanical components and layout as in Figure 2 (a),
- Instruction and practice via manual sketching and CAD modelling of various configurations and architectures of different real-world product internal component layouts as in Figure 2 (b), and
- Having students execute "forensic modelling" by completely disassembling and reassembling an entire high-technology product and while doing so measure and model in CAD every single part, component, dimension and detail (by the students' own admission, this process alone resulted in their learning more about real product design than in any other single way!).

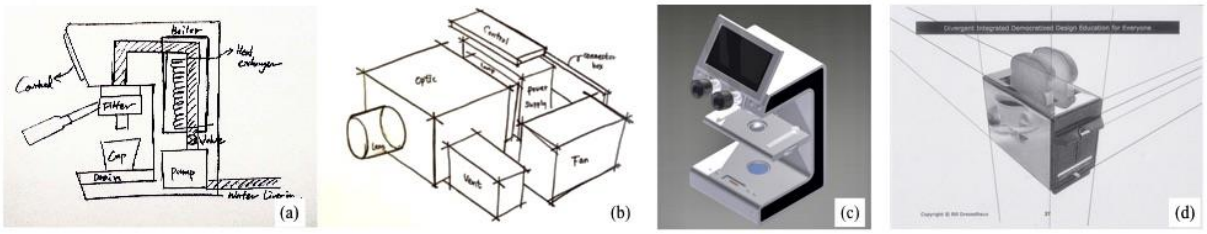

Figure 2. Internal components sketch (a), 3D configuration sketch (b), non-perspective CAD model (c), perspective view demonstration (d)

3 IMPROVED METHOD FOR AESTHETIC PRODUCT FORM DEVELOPMENT

As described previously, the students' difficulty with manual perspective sketching overwhelmed any reasonable expression of realistic product form—they simply could not sketch adequately enough to create and develop realistic perspective sketches. Thus a "detour" method was developed which resulted in a much improved educational outcome.

3.1 The improved form-giving method

As indicated, the engineering students could generally sketch orthographically. After a brief three-view orthographic drawing review, they were instructed to first sketch their basic product form concepts in simple orthographic two- and three-views for initial exploration. They then proceeded to develop their best initial ideas in CAD modelling for precise perspective realism and form detailing. Switching to this two-fold form development method—creating simple orthographic form sketches manually and then going directly to CAD modelling—worked incredibly well! This improved design methodology:

- Bypassed the intensive manual perspective form sketching, normally practiced by industrial designers, that engineering students were mostly incapable of,
- Used easily understood and created rough orthographic two- and three-view form concepts,
- Did not use extensive manual sketching or rendering as the final product form rendition but created final CAD-rendered photorealistic product form designs,
- Had the advantage of instructor design critiques being focused directly on the student 3D CAD product form models rather than dealing with manual sketching quality (or its lack thereof),
- Utilised CAD advantages over manual sketching, e.g., physical accuracy, unlimited viewpoints,

"perfect" perspective, model animation, easy form changes, and parametric variation, and
- Utilised visualisation methods known, familiar and practiced by most engineering students.

3.2 Student instruction in aesthetics and form development principles

To develop product designs, students were also trained in basic aesthetic design principles such as:

- Fundamentals of proportion, contrast, alignment, shape, space, size, colour, symmetry, position, stability, unity, balance, value, harmony, orientation, novelty, light, shadow, and composition,
- Utilising only simple geometric forms versus organic forms, surfaces, and aesthetics due to the complexity and difficulty of using organic forms, surfaces and aesthetics,
- Dominant, subdominant and subordinate geometric forms, intersections and combinations [9],
- Applying consistent and appropriate edge, intersection and corner radii and chamfers,
- Creating appropriate parting lines, gaps and reveals between product enclosure parts,
- Applying appropriate product materials, surface texture and colourisation,
- Developing product family "look and feel" designs of multiple products,
- Using ergonomic features on product functional and human interaction usability areas, and
- Integration of appropriate enclosure manufacturing principles with aesthetic form development.

3.3 Recurring difficulties in CAD perspective perception

As indicated previously, students often had difficulties in "seeing" and executing perspective. This perceptual problem was also observed as well in their early product form CAD models. Many of the students' failed in "seeing" and detecting perspective, or the lack thereof, in their own CAD model images such as in Figure 2 (c), even though in CAD it is a simple button click to switch to perspective view. To remedy this situation the following was done:

- Demonstrations of the visual reality of perspective using photos of actual objects, scenes and products with the indicated horizon line, vanishing lines and vanishing points as in Figure 2 (d),
- Quizzes given with images of various scenes, sketches and products that were in both perspective and non-perspective views where the students must identify the difference, and
- Exercises and quizzes that required the students to over-draw the horizon line and vanishing lines to the imaginary vanishing points on a photocopy image of an actual object, scene or product.

4 FINAL STUDENT WORK RESULTS

The students' final product design perspective sketching and aesthetic form work [10] was significantly improved and much more realistic and refined than their initial work, as shown in Figure 3. In the end, they successfully adapted to new perceptions and improved methods and created realistic product designs in both manual sketches and CAD models, each in a one-semester course timeframe. It is felt by the authors that much of their final work quality rivalled that of many competent industrial design students.

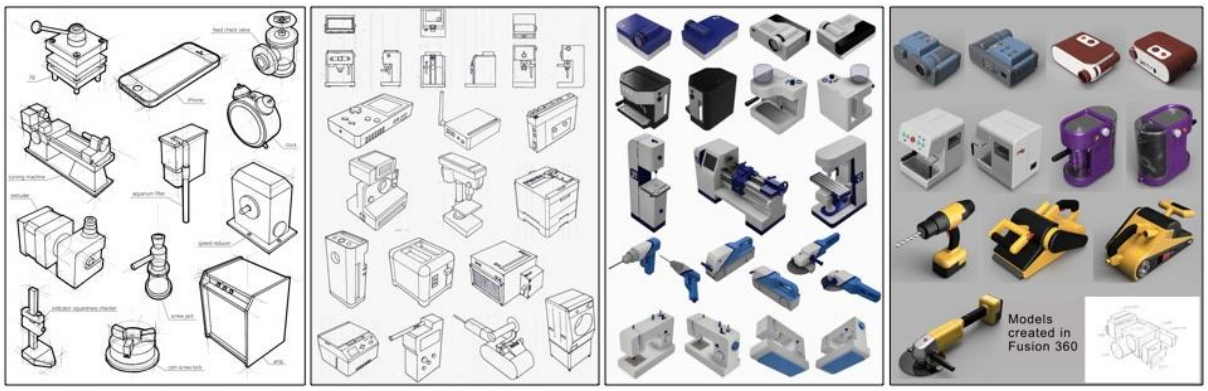

Figure 3. Final sample product sketching and aesthetic form posters of engineering students

5 CONCLUSIONS

The results of this programme indicate that realistic perspective sketching and aesthetic product form-giving are quite teachable to engineering students, but require the use of familiar tools and skills and improved instructional and execution methods as essential means for success. Using this approach, engineers can be educated as hybrid "Designeers" and create quality perspective sketches of products and machines, create designs of various products, tools and machines with proper layout configurations, include good ergonomics, functionality and usability into their product designs, and produce outstanding product design aesthetic forms. The authors feel there is a need for more rigorous research to better understand how to educate engineers in product design as well as in engineering design. One potential topic is the qualitative (and quantitative, if possible) comparison in effectiveness between the improved methods presented herein and the method of extensive manual sketching, as to which is the better means for product design concept development.

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