Building a Common Ground – The Use of Design Representation Cards for Enhancing Collaboration between Industrial Designers and Engineering Designers

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Building a Common Ground –

The Use of Design Representation Cards for Enhancing Collaboration between Industrial Designers and Engineering Designers

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Abstract

To achieve success in today's commercial environment, manufacturers have progressively adopted collaboration strategies. Industrial design has been increasingly used with engineering design to enhance competitiveness. Research between the two fields has been limited and existing collaboration methods have not achieved desired results.

This PhD research project investigated the level of collaboration between industrial designers and engineering designers. The aim is to develop an integration tool for enhanced collaboration, where a common language would improve communication and create shared knowledge.

An empirical research using questionnaires and observations identified 61 issues between industrial designers and engineering designers. The results were grouped and coded based on recurrence and importance, outlining 3 distinct problem categories in collaborative activity: conflicts in values and principles, differences in design representation, and education differences.

A taxonomy further helped categorise design representations into sketches, drawings, models and prototypes. This knowledge was indexed into cards to provide uniform definition of design representations with key information. They should benefit practitioners and educators by serving as a decision-making guide and support a collaborative working environment.

A pilot study first refined the layout and improved information access. The final validation involving interviews with practitioners revealed most respondents to be convinced that the tool would provide a common ground in design representations, contributing to enhanced collaboration. Additional interviews were sought from groups of final-year industrial design and engineering design students working together. Following their inter-disciplinary experience, nearly all respondents were certain that the cards would provide mutual understanding for greater product success.

Lastly, a case study approach tested the cards in an industry-based project. A design diary captured and analysed the researchers' activities and observations on a daily basis. It revealed positive feedback, reinforcing the benefits of the cards for successful collaboration in a multi-disciplinary environment.

Keywords

Industrial Design, Engineering Design, Collaboration, Design Representation, New Product Development.

In today's competitive environment, companies are under constant pressure to operate to optimum efficiency. In terms of the interaction between industrial designers and engineering designers, it has been noted that without managed collaboration, the direction of work can diverge and task fragmentation reduces efficiency (Jevnaker, 1998, Persson and Warell 2003).

This paper investigated the level of collaboration between industrial designers and engineering designers, outlining three distinct problem categories: conflicts in values and principles, differences in design representation, and education differences. The researchers propose an integration tool through the use of design representation cards, highlighting that common language can improve communication and create shared knowledge. This enhanced collaboration enables products to be developed more effectively, with less cost and higher profits.

Review of Related Research

Researchers have established that cross-functional cooperation leads to greater product development success (Jassawalla and Sashittal, 1998). Focused research into the interaction between industrial designers and engineering designers has been limited to several institutions, including TU Delft (DeKoven, et al., 1991) and Chalmers University where Persson (2002, 2005) proposed collaborative workspaces and joint social mindsets to enhance collaboration. Despite other methods, including better workspace arrangement and social organisation (Griffin and Hauser, 1996), significant results have not been achieved.

Research Aims and Objectives

The aim of this PhD-based research was to develop a tool for improved collaboration between industrial designers and engineering designers in design practice. It highlighted problems in conducting collaborative work through a lack of mechanisms to work efficiently.

New Product Development

New product development (NPD) begins by identifying product opportunities and ends with production, delivery and sales (Pahl and Beitz, 1995). The phases include concept design, design development, embodiment design and detail design (Ulrich and Eppinger 1995). Despite its advantages, cross-functional integration has drawbacks where joint involvement introduces conflicts. Different members have diverse orientations, goals and values that lead to conflicting expectations, disrupted work patterns and decreased productivity.

Industrial Design & Engineering Design

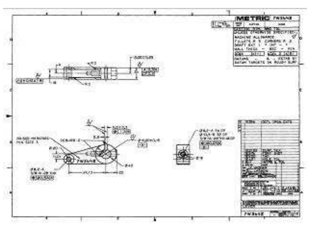
Although both industrial designers and engineering designers are concerned with designing, there are differences. Flurscheim (1983) pointed that industrial designers visualize the product and represent design solutions, achieve product unity, and adapt the product for the user. The Industrial Designers Association of America defines the profession as optimizing function, quality and appearance of products for the mutual benefit of both user and manufacturer (IDSA 2006).

Engineering design establishes and defines solutions through scientific knowledge, ensuring that market needs, specifications and production requirements are met (Hurst, 1999). While Fielden (1963) added that engineering design is a mix between mechanical, electrical and electronic engineering, Oakley (1990) highlighted that engineering designers do not produce artefacts but rather detailed descriptions for production.

In this research, industrial design refers to creating a product form, encompassing aesthetics, semantics, ergonomics and social aspects, including user needs. Engineering designers refers to technical activities that encompass science-based problem solving methods, including market needs, specification and production.

Differences between Industrial Designers and Engineering Designers

In differentiating working approaches, industrial designers prefer open-ended solutions, adopting trial-and-error and intuition to ensure individual expression to the design. Industrial designers view problems as ill-defined, while engineering design's view problems as distinct. This dissimilar view creates conflict (Persson and Warell 2003). Besides deep-seated differences in cognitive styles (Cross, 1985), another key difference is that industrial designers focus on appearance and user-interface; whereas engineering designers focus on functionality and manufacture (Kim, et al., 2006). The engineering design produces technical drawings (figure 1) for the manufacture of a working product based on quality, performance and cost (Flurscheim 1983). In contrast, industrial designers produce representations such as rendered sketches and 3D models (figure 2).



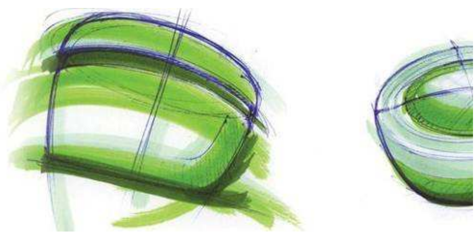


Figure 1: Technical drawings (left)   Figure 2: Rendered sketches (right)

In education, Rosenthal (1992) observed industrial design courses involving use of models, representation techniques and other soft skills. In contrast, Engineering designers are taught quantified hard science on cost, efficiency, function, control and operation. Recently, universities are beginning to integrate industrial design into engineering education. Engineering students at Loughborough University (2007) are taught design, analytical and manufacturing skills necessary to effectively develop new products Similarly, Stanford University offers mandatory courses in "visual thinking" for mechanical engineering undergraduates. Another encouraging aspect in interdisciplinary education is at Massachusetts Institute of Technology where students in industrial design, engineering design and manufacturing are taught cross-disciplinary skills. Although it is hoped that graduates would be equipped with such knowledge, only very few institutions offer interdisciplinary education opportunities.

Communication

Communication is crucial in design projects and poor communication hinders teamwork. Therefore, to avoid costly reworks, delays and to reduce lead-time, effective communication is important. Clark and Wheelwright (1993) proposed the importance of communication to achieve greater bonding and efficiency. This is highlighted by Chiu (2002) who suggested transmitting communication symbols precisely; ensuring symbols carry their meaning without interference; effectively receiving the intended meaning; and reaching the right audience through accurate distribution.

Despite these steps, studies increasingly showed that engineering designers do not understand the vocabulary used by industrial designers. Investigations by Fiske (1998) showed industrial designers found it difficult to understand engineering design -related issues such as technical specifications. In addition, words may not have the same meaning for all members. Persson and Warell (2003) added that communication becomes even more effective once the team develops a common vocabulary by understanding communicative codes and the language, e.g., symbols, product reproductions and message content.

Collaboration in Design

Collaboration is defined as working jointly together (Merriam-Webster, 2006). Kahn and Mentzer (1998) stated collaboration occurs when individuals with different, complementary skills work together, seeking collective goals, mutual understanding and share resources with a common vision. Jassawalla and Sashittal (1998) established that collaboration occurs when participants command equal interest; adopt transparency with high awareness; are mindful through integrated understanding; and with synergy.

Success is measured by achieving set goals in the design specification; and where collaboration was discussed earlier. Successful collaboration is the achievement of set goals through a shared process with mutual understanding and common vision. This can be accomplished using systematic tools, methods and procedures, including good communication, co-location, and social and technical elements (Paashuis, 1988).

Factors Influencing Collaboration between Industrial Designers and Engineering Designers

While interdisciplinary teams are considered necessary to achieve collaboration, they have shortcomings. Barriers to collaboration include misaligned expectations, insufficient resources, poor communication, lack of trust, personality differences and physical barriers (Griffin and Hauser, 1996). Differences in tools and education have made collaboration difficult. Engineering designers use systematic methods in solving problems. In contrast, industrial designers focus on social and cultural values, making it difficult for engineering designers to perceive accurately, resulting in unclear solutions (Warell 2001).

Each member has their own focus, experiences, competencies, responsibilities and inhabit different worlds, seeing the project differently (Svengren, 1995). As separate thought worlds develop, language barriers arise. Industrial designers use their own set of terms, and engineering designers use technical terms. The different languages and representations complicate shared understanding (Bucciarelli, 2002). Even more so, collaboration productivity is threatened by lack of common ground and vocabulary among members (Clark, 1996).

Erhorn and Stark (1994) noted that because each department has its own vocabulary suited to its activities, it has difficulty in communicating and understanding others, leading to errors. Although the language may be similar, identical words can have different meanings (Ashford 1969).

In summary, we find that collaboration and communication are intertwined. Despite available tools and methods to support effective collaboration, these approaches have not produced a common ground in achieving enhanced collaboration.

Research Procedure - A Qualitative Approach

The empirical study aims to investigate barriers occurring during collaborative design in new product development. The ten-week study interviewed 31 practitioners from 17 design consultancies specialising in consumer electronic products. Of these, we interviewed 10 industrial designers and 5 engineering designers who were from non-managerial positions. The remaining were made up of 16 respondents who held managerial or project leadership positions with an experienced background in industrial design and engineering design. The fieldwork constituted 45 hours of in-depth interviews and another 80 hours of observations. The empirical studies utilized qualitative research methodology, incorporating semi-structured interviews and observed participants in an industrial project.

Interview Study

The interviews comprised open-ended questions that allowed respondents to fully describe their personal experiences (Stauffer et al., 1991) related to group interaction, reasons for project success and failure, as well as methods used during the project. To improve reliability, a mix of large, medium and small companies with an equal number of industrial design and engineering design managers and non-managers were interviewed. Reliability was improved by re-checking results with the respondents.

	Issues	Company																	Occurances
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
1	Having knowledge of the other field					■	■	■	■	■		■			■		■		8
2	Conflict in Principles	■		■				■	■		■		■						6
3	Choosing the right tools and methods	■	■			■	■	■						■					6
4	Communication Skills	■					■			■				■	■			■	6
5	Use of Representation				■	■	■			■		■			■				6
6	Understanding each other			■	■							■			■		■		5
7	Fixed Engineering Mindset	■					■			■	■	■							5
8	Individual Differences & Attitude			■			■					■			■	■			5
9	Direction of Project Manager							■					■		■	■	■		5
10	Use of Rapid Prototype for Representation		■		■		■					■							4
11	Designers and Engineers having Different Values		■				■				■		■						4
12	Having a Common Goal			■			■								■				3
13	Get-together updates / Milestones						■		■						■				3
14	Informal Meetings	■					■								■				3
15	Understanding through Experience				■			■							■				3
16	Translation from 2D to 3D						■					■						■	3
17	Company Emphasis on Design or Engineering					■							■					■	3
18	Educational Background of Individual		■					■			■								3
19	Western vs Asian approach of working		■								■					■			3
20	Conflict in Interest	■						■											2
21	Fixed Working Protocols						■	■											2
22	Location of support members						■								■				2
23	Trust as a high-level understanding														■	■			2
24	Knowing the technical requirements						■					■							2
25	Working towards Joint-Solutions									■					■				2
26	Production & Manufacturing Limitations							■				■							2
27	Company Culture	■														■			2
28	Engineers do not Understand Role of Designers	■												■					2
29	Teamworking & Team Dynamics	■						■											2
30	Having standard Computer files			■			■												2
31	Limitations in Time leading to Poor Engineering						■											■	2
32	Limitations to size of Electronic Components												■				■		2
33	Creativity and Flexibility of Engineer					■				■									2
34	Marketing controls Budget affecting Design Quality		■											■					2
35	Language as a Probable Barrier				■					■									2
36	Knowing who is in charge / Roles & Responsibilities										■			■					2
37	Team Dynamics							■											1
38	Being specific				■														1
39	Designers getting carried away & fall behind time										■								1
40	Using standard codes				■														1
41	Having Multi-cultural Teams														■				1
42	Having Multi-disciplinary Teams														■				1
43	Fostering Team-spirit														■				1
44	Complexity of Project											■							1
45	Marketing Understand Designers Working				■														1
46	Designers Understand Manufacturing Constrains									■									1
47	Testing, Reviewing, Changing, Refining														■				1
48	Marketing should be faster to React														■				1
49	Engineering Issues affecting Design Aesthetics														■				1
50	Client Changes affecting Design Process				■														1
51	Designers not understanding Marketing Viewpoint	■																	1
52	Trimming Cost affecting Design Aesthetics						■												1
53	Difficulty in Explaining visual effects to Engineers											■							1
54	How Company & Organization Values each field																	■	1
55	Software Incompetence																	■	1
56	Proper justification for each decision to Understand																■		1
57	Using Technology for Enhanced Communication												■						1
58	Changes in Design due to Safety Requirements					■													1
59	Client Involvement in Design Stage							■											1
60	Education as a means to close gap btw Eng & Des										■								1
61	Difference between a Designer and Artist			■															1

Figure 3: Matrix of 61 problem categories tabulated from interviews

Interview Results

The data was first encoded into a spreadsheet which identified 61 problem categories. By adopting Lofthouse's (2001) coding and clustering technique, the results were then condensed into a matrix based on recurrence and importance. The matrix highlighted 19 most frequently occurring problems (occurring 3 or more times), further categorised into three distinct headings shown in the right-most column of figure 3. Each category is now discussed:

1. Problem category A - Conflict in values and principles

The results identified differences in values and working principles. Engineering designers work in a logical way with quantified solutions based on efficiency or cost. In contrast, industrial designers favoured an open-ended approach and adopt open solutions. In three companies, working protocols were implemented to standardize procedures. Feedback showed that it was difficult for the industrial designers to follow working procedures, e.g., requiring correct dimensions at early stages of design.

2. Problem category B - Differences in design representation

The investigations noted the impact of the different methods of representations used by industrial designers and engineering designers. It was recognised that engineering designers tended to favour technical jargon and facts including calculations, technical information and specifications. Industrial designers preferred freehand sketches to communicate ideas. It was also noted that the engineering designers had problems in understanding the sketches. The findings concluded the lack of a common medium for both disciplines represented an obstacle towards effective collaboration.

3. Problem category C - Education differences

Due to differences in background and education, it was found that members had different specialisations, approaches and expectations. Both disciplines had different focus: engineering designers adopted systematic problem solving and justified solutions with facts; whereas industrial designers solved problems intuitively, rarely relying on quantified data.

Observation Study

Observations were used to allow researchers obtain detailed information by being close to the field of study. The 2-week study was based on the design of an electronic communication device requiring industrial design and ED collaboration. It was conducted with a design consultancy within a normal work environment. It took place from the start of the project and ended at the embodiment design stage. The observations focused on the project leader, industrial design and ED. Data collection was carried out by note-taking due to confidentiality. The drawback was that it could not fully describe the whole situation.

Reliability was achieved by avoiding interruptions during the process and clarifications made during breaks. Company-specific documents, including reports, specification lists and physical or virtual artefacts provided additional information.

Observation Results

The Observation studies identified that:

1. Formal and informal meetings were valuable for healthy discussion and increased collaboration opportunities.
2. Co-located members in close proximity enhanced collaboration.
3. Different approaches in the design process affected collaboration. Engineering designers focused on technical properties and cost, whilst industrial designers emphasised more on form and expression.
4. Problems in translating a 2D hand-sketch to digital 3D CAD model affected the working process.
5. The lack of a common language in design representations added difficulty for industrial designers and engineering designers to understand each other.

Summary of Findings

From the interview study, we found three problem categories in collaborative design: A). Conflict in values and principles; B) Differences in design representation; C) Education differences. In addition, the observation study found key elements discussed in section 3.2.1 to be present in collaborative design.

Overview of Design Representations

A representation is defined as a model of the object it symbolises (Palmer, 1987). Internal representations encompass imagery and cognitive activity. External representations are visual or verbal (Goel, 1995; Goldschmidt, 1997) and are expressed through language, graphics or actual objects. This research focuses on external representations encompassing physical and digital formats.

In the early stages when the object is not materialised, unstructured representations such as sketches are used. As the design develops, structured forms including drawings appear. Leonard-Barton (1991) discussed the increasing realism from two to three-dimensional representations, e.g. from sketches to prototypes that resemble the final product. The increased realism adds information and enhances product understanding.

Applications of Design Representations

According to Tang (1991), sketching allows visualisation, communication and information storage, while Larkin and Simon (1987) pointed that representations externalised and visualised problems. Other studies highlighted the importance of product representations in enhancing team communication (Ulrich and Eppinger 1995), and as a thinking tool (Ferguson, 1992). Suwa, Purcell and Gero (1998) found sketches provided visual cues for further work and for functional thoughts to be constructed. Other uses of representations include "referential sketches" to record observations and discoveries (Graves, 1977); to verify decisions (Herbert 1993); and to allow a range of interpretations to a design solution (Scrivener 2000).

Categories of Design Representations

Sketching and drawing with paper and pencil best serve as fast representations for early design. Other design representations include scale models, prototypes, mock-ups, CAD and virtual reality. Tovey (1989) proposed categorising representations into traditional methods, verbal-numerical and visuo-spatial methods, further ranked as undetailed to detailed. Herbert (1987) analysed marks on representations and defined them as free-hand sketches, draft principle marks, text annotations, dimensions, and calculation marks.

Design representations employed by industrial designers and engineering designers were identified (Tovey, 1989; Ferguson 1992; Do et al., 2000; Veveris, 1994; Author, 1992; Otto and Wood, 2001) and a taxonomy was created that classified design representations into sketches; drawings; models; and prototypes (Figure 4).

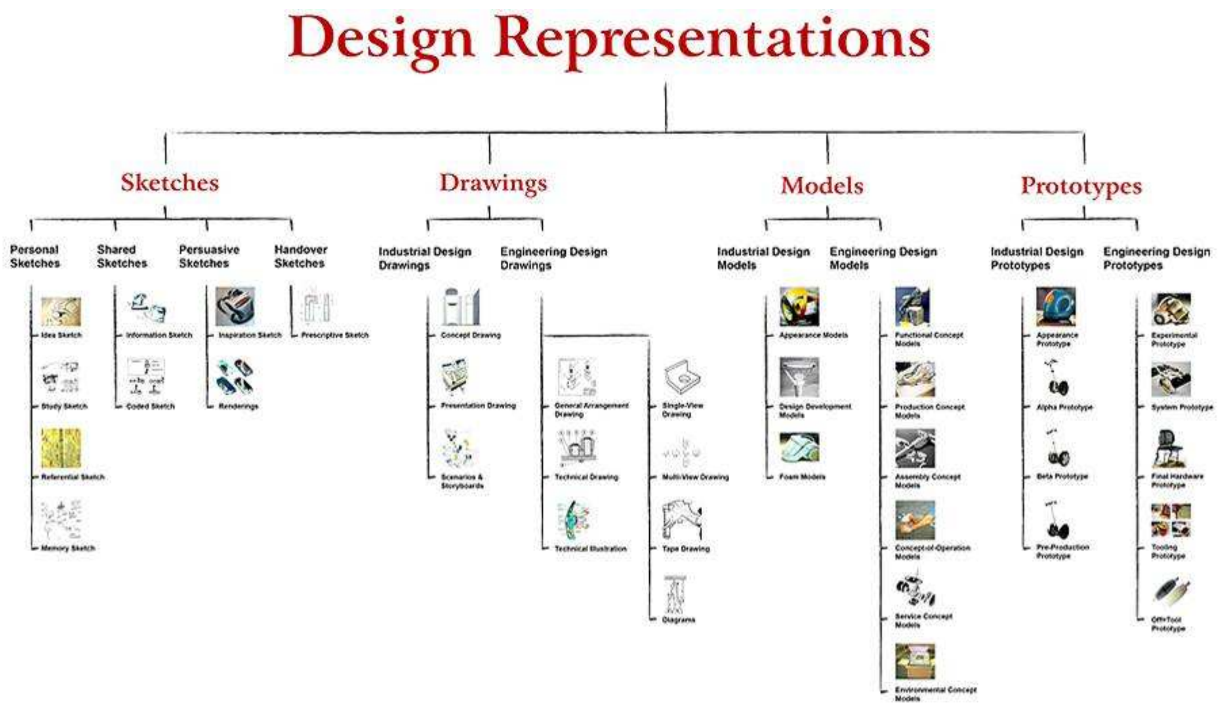


Figure 4: Taxonomy of Design Representations

Issues in Design Representations

Sketches are sometimes incomplete and can be interpreted differently. Being ambiguous enables designers to re-interpret them and gain new insights (Goel, 1995). While ambiguity can help spark new designs and facilitate negotiation, it can be inaccurate and inconsistent.

Representations must be consistent across members. To bridge this gap, some professions have standardized formal systems such as ISO standards and engineering terminology. The design profession however, has less established representations that are ill-defined and imprecise (Saddler, 2001). Consequently, industrial designers apply drawing conventions that make it hard for engineering designers to comprehend and in recognizing how the aesthetical solutions work in relation to product's technical aspects. Highlighting differences in the vocabulary of each discipline, Matthew (1997) suggested having a common understanding of shared definitions. By having a common ground in representations, communication and interaction would be enhanced, leading to improved collaboration.

Proposed Design Tool

Successful collaboration is the achievement of set goals through a shared process with mutual understanding and common vision. It is an activity that requires information sharing, good communication and shared knowledge. We use the points below as the basis for a design aid that would support collaborative working environment between industrial designers and engineering designers:

1. The design profession has representations that are ill-defined, imprecise and lacking in communicative power (Saddler, 2001).

2. As each discipline has a unique vocabulary, this can be improved by having a common understanding of the shared definitions (Matthew 1997).

3. A common vocabulary can be realized by understanding communicative codes and language (Persson and Warell, 2003).

4. This common vocabulary requires transmitting communication symbols precisely; ensuring symbols carry their meaning without interference; effectively receiving the intended meaning; and reaching the right audience through accurate distribution (Chiu 2002).

Aims and Objectives of Design Representation Cards

The aim of the design representation cards was to provide a uniform definition of design representations, thus providing industrial designers and engineering designers with a common vocabulary. The tool would include key design and technical information, consequently serving as a decision-making guide. The tool would help identify representations used during design stages, allowing users to be aware of each others working processes for effective planning.

Format and Layout of the Cards

Numerous formats, including matrices, flowcharts, wheel diagrams, rolodex, websites and software versions were created and internally validated. The cards were chosen as its physical format would encourage personal interaction between users. In addition, colour coding would allow users identify content quickly. Red cards would show information on industrial design practice; and blue cards showing ED practice.

The cards would include the following key content:

1. Design Stages:	Information regarding the stages of NPD would allow users to gain an overview of the design process, serving as an introduction.

2. Design Information:	Key design information related to ID work processes, including data on form and detail, visual character, colour, etc.
Technical Information:	Key technical information related to ED work processes, including data on mechanism, assembly, construction, etc.
Design Representations:	A compilation of representations used by industrial designers and engineering designers, categorised into sketches, drawings, models and prototypes.

Card Structure

The cards were divided into 3 sections. Pack 1 (figure 5) illustrates key design stages of the NPD process. The front face presents a definition of the design stages where industrial designers and engineering designers collaborate during the design process. The back shows information about the types of design representations used.

Figure 5: Pack 1 – Key stages of the NPD process

Pack 2 (figure 6) describes key design and technical information used by industrial designers and engineering designers in the design process. The front face shows the definition of design and technical information used by industrial designers and engineering designers. The back face shows representations that are related to the design or technical information.

Figure 6: Pack 2 – Key design and technical information

Pack 3 (figure 7) gives the representations (discussed in 4.2) used by industrial designers and engineering designers in the design process. The front face shows definitions of the design representation and the reverse face shows design and technical information present in the representation and illustrates the popularity of the representation in a design stage.

Figure 7: Pack 3 – Design Representations used by industrial designers and engineering designers

Using the Cards

For CoLab to be implemented, concordance must be present where stakeholders first agree to work towards a common goal (Pawar et. Al. 1999), building a neutral ground among members. In order to explain how CoLab could be used, let us create a scenario whereby an engineering designer wants to know more about an industrial designers' referential sketch and identify whether form and detail is exemplified in these sketches:

Step 1: Choose the right coloured set

The engineering designer first chooses the red set that represents industrial design practice.

Step 2: Refer to the relevant pack

The cards are categorised into 3 packs within the red set. The engineering designer then chooses the pack on design representations where referential sketches would be found.

Step 3: Finding information within the card

The definition of referential sketches can be obtained on the front of the card with an accompanying visual that shows how referential sketches look like. The back of the card illustrates information related to the referential sketch. The numbers and bar charts show the popularity of the information being adopted by industrial designers (since it is a red card) within the industry.

Benefits of the Cards

The physical cards provide efficient sharing of data with portable and instant access to information without the need for a computer or internet access. It supports collaboration and information sharing by allowing industrial designers, engineering designers or external stakeholders to gain a better understanding of the design stages and representations used. More importantly, the cards enable the development of a common vocabulary, creating shared knowledge. With this shared knowledge, they are able to build a unified cognitive frame with awareness of working processes. Users are able to plan their work more effectively and individuals can anticipate, rather react to each other's behaviour.

Pilot Validation

Pilot validation through interviews with industrial design and engineering design refined the layout, including key suggestions to adopt a numerical system for faster information access and enlarging to ISO B8 size (62×88 mm), a standard for today's playing cards that would improve readability. Other improvements include a more professional design with concise text (figure 8). The size of the images was increased along with their resolution. The background was produced in two colour tones for less visual clutter.

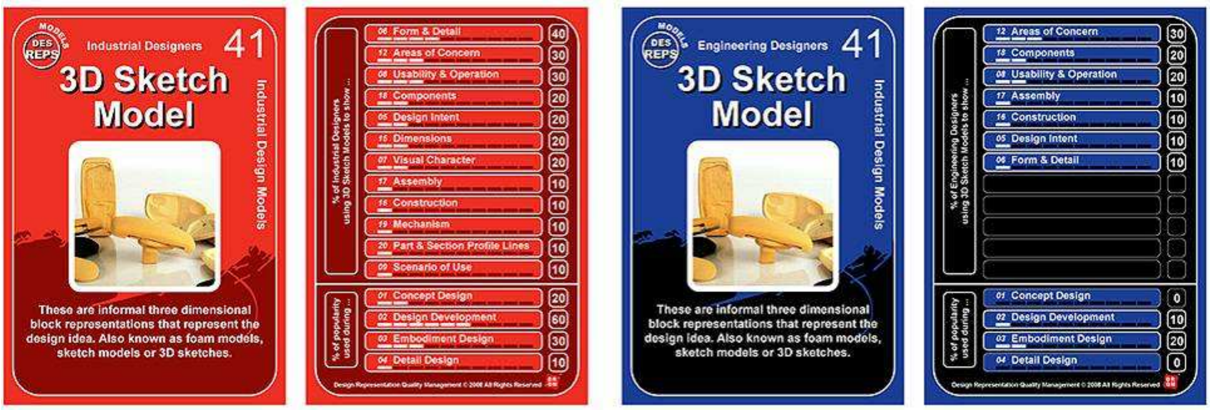


Figure 8: Improved version of the cards after pilot validation

Final Validation with Industry Interviews

The final validation employed a 3-phase process. The first phase involved semi-structured interviews with 43 participants from 15 design companies and academic institutions. Of these, we interviewed 22 industrial designers and 21 engineering designers. The questions comprised of a set of statements referring to the format, layout and if the cards would be improve design collaboration. The respondents could either agree or disagree according to a five-point Likert scale, with a 'neutral' option.

When asked about the physical card format, 86.4% of industrial designers and 89.5% of engineering designers gave a positive rating. There was equal positive feedback by industrial designers (86.4%) and engineering designers (89.5%) who agreed the tool would provide them with enhanced understanding and clearer definition of design representations. The respondents (industrial designers 86.4%; engineering designers 84.2%) also agreed that the system would create a common understanding of design representations.

When asked if the system would foster enhanced collaboration, there was a general positive outcome with only 4.5% of industrial designers giving a poor rating and 27.3% of industrial designers being neutral. There were no poor ratings from the engineering designers and 36.8% gave a neutral feedback. The results indicated that most respondents felt that the tool would provide a common ground in design representations, contributing to enhanced collaboration.

Final Validation with Student Interviews

The second phase sought four groups 18 final year industrial design and engineering design undergraduates working together in an industry-based project. Following their experience in inter-disciplinary collaboration, the students were given the same interview questions to determine if their project could have been enhanced with the use of the cards.

All industrial design students (100%) and 92.9% of engineering design students giving a positive feedback about the format. All industrial design students (100%) and 85.5% of engineering design students felt the tool would provide an enhanced understanding and clearer definition of design representations. 66.7% of industrial design students and 64.3% of engineering design students felt the cards would be effective in creating common understanding of design representations between industrial designers and engineering designers. Importantly, all (100%) industrial design students and 85.8% of engineering design students felt that the tool would foster enhanced collaboration between them.

The second phase of validation provided positive feedback in that the system would help achieve a common language and build mutual understanding for greater product success.

Final Validation with Case Study & Design Diary

Finally, a 3-week case study tested the cards in an industry-based project. The case study approach allowed the investigation of the cards within a real-life context (Yin, 1989). The observations were conducted within the natural work environment to obtain an immersive experience. A design diary proposed by Pedgley (2007) captured and analysed activities and observations on a daily basis.

The case study validated the design representations practiced by industrial designers and engineering designers during the project and the use of design and technical information. Importantly, the cards were shown to be useful as a clarification tool during the design process. In the third-week, it was recorded that both teams of industrial designers and engineering designers used identical keywords picked up from the cards during discussions which greatly minimised misunderstandings. In summary, the case study obtained positive feedback, reinforcing the benefits of the cards for successful collaboration in a multi-disciplinary environment.

Conclusion

The use of design representation cards was found to build a common ground between industrial designers and engineering designers, effectively enhancing collaboration. By having a unified understanding of shared definitions, representations would be more precise and effective. The benefits of the cards were affirmed from feedback including 15 design companies and academic institutions in a 3-phase validation process.

More importantly, this research contributed new insights into factors that have a detrimental impact on collaboration, namely: conflicts in values and principles; differences in design representation; and education differences. In addition, the research proposed a taxonomy of design representations, clearly defining sketches, drawings, models and prototypes used by industrial designers and engineering designers in the new product design process.

The authors propose future work to include refinements to the design representation cards and to seek commercial interest in production.

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References

Ashford, F. (1969). *The Aesthetics of Engineering Design*. London, Business Books Ltd.

Bucciarelli, L. L. (2002) Between thought and object in engineering design, *Design Studies* 23 (3)

Chiu, M.-L. (2002). "An Organizational View of Design Communication in Design Collaboration." *Design Studies* 23 (2).

Clark, K. B. and Wheelwright, S. C. (1993). Managing New Product and Process Development. In: The *Organization of Integrated Product Development*. V. Paashuis. Berlin, Springer-Verlag.

Clark, H. (1996): *Using Language*. Cambridge University Press.

Cross, N. (1985). Styles of learning, designing and computing. Design Studies (12) *Models of the design process*: integrating across the disciplines. N. F. M. Roozenburg and N. G. Cross.

DeKoven, E., Keyson, D. V., and Freudenthal, A. (2001). Designing collaboration in consumer products. In CHI '01 *Extended Abstracts on Human Factors in Computing Systems.* CHI '01. ACM, NY, pp.195-196.

Do, Y.-L., Gross, M. D., Neiman, B., Zimring, C. (2000) Intentions in and relations among design drawings. *Design Studies* 21(5)

Erhorn, C. and Stark J. (1994). *Competing by Design - Creating Value and Market Advantage in New Product Development*. Oliver Wight Publications, US.

Evans, M. A. (1992) Model or prototype which, when and why? Idater 92. In: Judson, H. F. *The search for solutions*. Hutchinson, (1980) pp.112.

Ferguson, E. S. (1992) *Engineering and the mind's eye.* MIT Press, Cambridge, MA

Flelden, G. B. R. (1963) *Engineering design.* H.M.S.O., London

Fiske, J. (1998) Kommunikationsteorier: en introduktion. Wahlström och Widstrand In: *Relational Modes between Industrial Design and Engineering Design – a Conceptual Model for Interdisciplinary Design Work.* Sara Persson and Anders Warell. Chalmers University, Göteborg, Sweden.

Flurscheim, C. H. (1983). *Industrial Design in Engineering*. London, The Design Council.

Goel, V. (1995) *Sketches of thought.* MIT Press, Cambridge, MA

Goldschmidt, G. (1997) Capturing indeterminism: representation in the design problem space *Design Studies* 18(4)

Graves, M. (1977). The necessity for drawing: Tangible speculation. *Architectural Design* 6, pp.384–394.

Griffin, A. and Hauser, J. R. (1996) Integrating R&D, and marketing: a review, and analysis of the literature. *Journal of Product Innovation Management* (13) pp.191 -215.

Herbert, D. (1987). Study drawings in architectural design: Applications of CAD systems. *Proc. 1987 Workshop of the Association for Computer Aided Design in Architecture* (ACADIA) pp.157.

Herbert, D. M. (1993). *Architectural Study Drawings*. New York: Van Nostrand Reinhold.

Hurst, K. (1999). *Engineering Design Principles*. New York, Arnold Publishers.

IDSA (2006). *About Industrial Design*. Retrieved 2 Feb 2006, from http://www.idsa.org/webmodules/articles/anmviewer.asp?a=89&z=23.

Jassawalla, A. R. and Sashittal, H. C. (1998). "An Examination of Collaboration in High-Technology NPD Processes." In: *Journal of Product Innovation Management* 15(3) pp.237 - 254.

Jevnaker, B. H. (1998) "Building Up Organizational Capabilities in Design", In: Bruce M. and Jevnaker, B. H. (eds.) *Management of Design Alliances*, Wiley, Chichester, England.

Kahn, K. B. and Mentzer J. T. (1998). "Marketing's Integration with Other Departments." *Journal of Business Research* 42(1) pp. 53 - 62.

Kim, Y. S., Philpott, M. and Arends, M. (2006). "*Interdisciplinary Research: Integrated Engineering and Industrial Design*." Retrieved 16 May 2006, from http://www.engr.uiuc.edu/communications/engineering_research/1996/gen1/gen1-9.html

Larkin, J. H. and Simon, H. A. (1987). "*Why a Diagram is (sometimes) Worth Ten Thousand Words.*" Cognitive Science Journal (11) pp.65-99

Leonard-Barton, D. (1991), Inanimate integrators: a block of wood speaks, *Design Management Journal*, Summer 1991, pp.61-67.

Lofthouse, V. (2001). PhD Thesis: *Facilitating Ecodesign in an Industrial Design Context: An Exploratory Study*. School of Industrial and Manufacturing Science, Cranfield University.

Loughborough University (2007). *Product Design and Manufacture, Undergraduate Prospectus.* Retrieved 2 March 2008, from http://www.lboro.ac.uk/prospectus/ug/dept/mm/pdm/index.htm

Mathew, B. S. Jr. (1997) Are traditional management tools sufficient for diverse teams? *Team Performance Management* 3(1) pp.3-11.

Merriam-Webster (2006). *Merriam-Webster's Collegiate Dictionary*. Retrieved on 6 January 2007 from http://m-w.com.cgi-bin/dictionary

Oakley, M. (1990). *Design Management* - A Handbook of Issues and Methods. Oxford, Blackwell Ltd.

Otto, K. and Wood, K. (2001) Product Design. *Techniques in Reverse Engineering and new Product Development*, Prentice Hall, New Jersey

Paashuis, V. (1988). *The Organisation of Integrated Product Development*. Springer Verlag. London.

Pahl, G. and Beitz, W. (1995). *Engineering Design*, 2nd edition (translated by Wallace, K.M., Blessing L. and Bauert, F.). Springer-Verlag, London.

Palmer, S. E. (1987) Fundamental Aspects of Cognitive Representation, In: E. Roch, B. B. Lloyds (Eds.), *Cognition and Categorization*, Lawrence Erlbaum Associates, Hillsdale, NJ.

Pedgley, O. (2007). "Capturing and analysing own design activity". *Design Studies* 28(5) pp.463-483.

Persson, S. (2002). *Industrial Design - Engineering Design Interaction*. Chalmers University, Göteborg, Sweden.

Persson, S. (2005). Toward *Enhanced Interaction between Engineering Design and Industrial Design*. Chalmers University, Göteborg, Sweden.

Persson, S. and Warell, A. (2003). *Relational Modes between Industrial Design and Engineering Design - a Conceptual Model for Interdisciplinary Design Work*. 6th Asian Design International Conference, Tsukuba, Chalmers University.

Rosenthal, S. R. (1992). *Effective Product Design and Development – How to cut lead time & increase customer satisfaction*, Richard D. Irwin Inc.

Saddler, H. J. (2001) Understanding Design Representations. *Interactions* July – August 2001

Stauffer, L. A., Diteman, M., Hyde, R. (1991). "Eliciting and Analysing Subjective Data about Engineering Design." *Journal of Engineering Design* 2(4).

Scrivener, S. A . R. , Ball, L. J., Woodcock, A. (2000). *Collaborative Design: Proceedings of Co-Designing 2000*. London, Springer-Verlag Ltd.

Suwa, M., Purcell, T. and Gero, J. 'Macroscopic analysis of design processes based on a scheme for coding designer's cognitive actions' *Design Studies* Vol 19(4) pp.455–483

Svengren, L. (1995). Industriell design som strategisk resurs. In PhD Thesis: *Toward Enhanced Interaction between Engineering Design and Industrial Design.* S. Persson. Chalmers University, Göteborg, Sweden.

Tang, J. C. (1991) Findings from observational studies of collaborative work. *International Journal of Man-Machine Studies* (34) pp.143-160

Tovey, M. (1989). "Drawing and CAD in Industrial Design." *Design Studies* 10(1).

Ulrich, K. T. and Eppinger, S.D. (1995). *Product Design and Development.* McGraw-Hill Book, Inc.

Veveris, M. (1994) *The importance of the use of physical engineering models in design*, Idater 94 Loughborough University

Warell, A. (2001). PhD Thesis: Design Syntactics: A Functional Approach to Visual Product Form. In: *Relational Modes between Industrial Design and Engineering Design - a Conceptual Model for Interdisciplinary Design Work*. S. Persson and A. Warell, Chalmers University, Göteborg, Sweden.

Yin, K. (1989) *Case Study Research*, Sage Publications. Newbury Park, CA

Figure 1: Detail drawing that includes three orthographic views from Bertoline, G. R. (2002) *Introduction to Graphics Communications for Engineers* (2nd Ed.). New York, McGraw Hill.

Figure 2: An industrial designer's sketch and 3D models from Zampach, M. (2006)

"*Personal Portfolio*." Retrieved on: 29 Nov 2006 http://martin.zampach.com

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After graduating from Brunel University in 1985, Dr Campbell worked as a design engineer in Ford Motor Company. He moved to the Rover Group in 1986 where again he was employed as a design engineer. In 1989, Dr Campbell was appointed as a Senior Teaching Fellow for CAD/CAM at the University of Warwick. In 1993, Dr Campbell obtained a lectureship at the University of Nottingham and gained his PhD through part-time study in 1998. His current position is Reader in Computer Aided Product Design at Loughborough University in the Department of Design and Technology where he is leader of the Design Practice Research Group. Dr Campbell is editor of the Rapid Prototyping Journal.

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