Making the Tacit Explicit: Developing Tools to Support Collaboration During Industrial Design and Engineering Design Practice

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Abstract

Industrial designers employ an extensive range of media and techniques at various times during professional practice. Whilst general patterns of use are acknowledged, such as loose sketches at the beginning of product development and full prototypes at the end, the nuances of use for specific design representations remain elusive. Having identified problems in communication during product development, the researchers identified a lack of understanding in the use of design representations as a key issue. This paper reports on research to enhance communication during product development by making tacit knowledge on the use of design representations explicit. This was achieved through the development of two design tools called CoLab and iD Cards. Phase 1 of the project identified barriers to communication through semi-structured interviews with 61 industrial designers and engineering designers at 17 industrial design consultancies. Phase 2 explored the nature of design representations and categorized 35 types as sketches, drawings, models or prototypes using isemi-structured interviews with both industrial designers and engineering designers, with differences in use between the two groups becoming apparent. Phase 3 used a process of information design to translated the findings and data from Phase 2 into the card-based CoLab design tool that included the taxonomy and indication of when the design representations were used by industrial designers and engineering designers and for what types of information. Changes were made after appraisal and the final tool was validated through semi-structured interviews with 43 industrial design and engineering design practitioners and observation. Phase 4 disseminated the research output with the support of the Royal Academy of Engineering (RAE) in the UK (CoLab web-based design tool) and Industrial Designers Society of America (IDSA) in the USA (iD Cards physical design tool). The paper concludes that the use of appropriate research methods that integrate literature based sources with practitioner engagement has the potential to elicit valuable and unexpected tacit knowledge. It also acknowledges that whilst the outcomes from such research can be enthusiastically received, translation into a format for effective dissemination can be a challenging and time-consuming process. However, with confidence in outcomes and a desire to disseminate, opportunities can be identified if researchers are prepared to be flexible and adapt to stakeholder needs.

Keywords

Industrial Design, Product Design, Engineering Design, Design Tools, Collaboration

Introduction

The complex and competitive nature of product development requires collaboration between design professionals to effectively conceptualise, develop and commercialise innovative products (Edmondson and Nemhard, 2009). Despite the importance of inter-disciplinary collaboration, few studies have examined the relationship between industrial design and engineering design. In the context of this study, industrial design is defined as the specification of product form and includes aesthetic judgement, semantics, user interface and social requirements (IDSA, 2006; Tovey, 1994; Flurscheim, 1983). In contrast, the term engineering design broadly encompasses mechanical, electrical and electronic engineering (Fielden, 1963), all of which employ science-based problem solving methods (Hurst, 1999).

The aim of the research was to investigate problems associated with collaborative interaction between industrial designers and engineering designers. Disharmony during NPD may occur when team members approach a project differently. For example, industrial designers adopt open-ended solutions, using instinct and trial-and-error to embody personal creativity for the design; whilst engineering designers view problems as precise and focus on functionality, specification and performance (Kim and Philpott, 2006). In terms of deliverables, engineering designers produce technical details for manufacture, based on quality, performance and cost (Flurscheim, 1983); while industrial designers deliver visual representations such as sketches and physical models. As a result, their dissimilar views and contrasting outcomes may create conflict (Persson, 2002).

Previous research has focused on inter-disciplinary collaboration between engineering design and manufacturing (Beskow, 1997; Ulrich and Eppinger, 2000) and engineering with marketing (Griffin and Hauser, 1996; Shaw and Shaw, 1998). With the exception of Persson and Warell (2003), who identified methods and tools adopted by industrial designers and engineering designers, research to investigate the collaborative interaction between industrial designers and engineering designers is under-represented. Persson and Warell (ibid) reported that communication, social factors, personality differences and physical settings were key factors in influencing professional interaction. Persson (2005) went on to propose a collaborative workspace with a joint mindset by means of socialisation and mediating instruments to enhance collaboration. Other integrating mechanisms included social organisation (Kahn, 1996; Jassawalla and Sashittal, 1998), the use of inter-communal negotiation for better cross-functional teamwork (Brown and Duguid, 2001), having boundary-spanning and good teaming skills (Edmondson and Nemhard, 2009), and employing information and communication technology (Sproull and Kiesler, 1991; Toye, et al. 1993). Although other established methods, such as Quality Function Deployment (QFD) and stage-gate solutions are available (Ulrich and Eppinger, 2000), they are primarily designed for engineers. As such, very few integrating mechanisms are available to enable, facilitate or improve collaboration been industrial designers and engineering designers.

Rothwell (1992) proposed that effective communication and cross-functional linkages are the primary factors for successful NPD. Communication can be made effective by transmitting symbols precisely, ensuring that the meaning is relayed correctly, receiving the intended meaning accurately, and reaching the right audience through proper distribution (Chiu, 2002). Although communication mechanisms exist, researchers have observed that industrial designers and engineering designers still do not fully understand each (Fiske, 1998). Communication only becomes accurate and effective when the team develops a common vocabulary and by understanding the communicative codes and language within the message content (Persson and Warell, 2003). In addition, collaboration represents a higher level relationship when compared to communication that is limited to information exchange. Jassawalla and Sashittal (1998) stated that collaboration occurs when participants command equal interest, adopt transparency with high awareness, are mindful through integrated understanding, and perform with synergy. Collaboration allows members from different teams to divide work effectively, assist each other in maximising their joint contribution, and communicating accurate information such as through the use of precise design representations.

In the context of an opportunity to enhance collaboration between industrial designers and engineering designers by standardising language, developing awareness of methods and identifying differences in the use of design representations, the authors defined a methodology that would generate a taxonomy of design representations and then be used to collect empirical data that would confirm accuracy and identify on when they were used and for what types of information by the two groups. By standardizing language and providing a level of understanding of how industrial designers and engineering designers use design representations, a knowledge framework would be generated with the potential to translate into some form of design tool.

Phase 1: Identification of Barriers to Communication

Interviews

Semi-structured Interviews were undertaken with experienced industrial designers, engineering designers and design managers from 17 industrial design consultancies specialising in consumer electronic products. There was a balance of large (more than 10 design staff), medium (between 6-10 design staff) and small industrial design consultancies (less than 5 designers) to allow a wider sampling and to obtain findings from a larger pool of respondents. 61 semi-structured interviews were conducted. A semi-structured interview was selected as this method had the capacity to explore issues with the potential for respondents to fully describe personal experiences relating to group interaction and inter-disciplinary collaboration. After gathering general demographic data (educational background, work experience and the company structure) the participants were asked project-specific questions to identify factors relating to collaborative work. This required an example of a project, experiences of group interaction, reasons for project successes and failures, and an indication of the tools and methods used for the project. The questions can be seen in Table 1.

Table 1: Questions used during semi-structured interviews

Research-specific questions
1. Describe a recent project undertaken
2. Describe the design approach and strategy adopted
3. What was the project deliverable?
4. What activities were involved?
5. Describe the tools and methods used
6. What design representation methods were used?
7. Did collaboration between industrial designers and engineering designers occur during the project?
8. Describe the quality of group interaction and teamwork
9. What factors might have influenced group work?
10. Were there any leadership or management issues?
11. Name the success or failure factors
12. What is your view of the final product?
13. Did you have any personal concerns working with the other discipline?
14. Suggest some improvements for future collaborative work

The interviews identified issues relating to inter-disciplinary collaboration which were encoded into a spreadsheet. A coding and clustering technique was then used to analyse the qualitative data and to help build theory (Miles and Huberman, 1994), as well as reducing data into themes and relationships (Strauss and Corbin, 1990). This pattern coding has been used by other researchers (Purcell *et al*., 1996) in order to summarise findings into condensed categories. The issues were re-organised with the most frequently occurring problems in a descending order as shown on the right column of the chart in Table 2.

Table 2: Matrix of 61 problem categories tabulated from interviews

	Issues	**Company**																	**Occurances**	**Category**
		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	A
2	Conflict in Principles	■		■				■	■		■		■						6	A
3	Choosing the right tools and methods	■	■			■	■	■						■					6	B
4	Communication Skills	■					■			■				■	■			■	6	B
5	Use of Representation				■	■	■			■		■			■				6	B
6	Understanding each other			■	■							■			■		■		5	A
7	Fixed Engineering Mindset	■					■			■	■	■							5	C
8	Individual Differences & Attitude			■			■					■			■	■			5	C
9	Direction of Project Manager							■					■		■	■	■		5	A
10	Use of Rapid Prototype for Representation		■		■		■					■							4	B
11	Designers and Engineers having Different Values		■				■				■		■						4	C
12	Having a Common Goal			■			■								■				3	A
13	Get-together updates / Milestones						■		■						■				3	B
14	Informal Meetings	■					■								■				3	A
15	Understanding through Experience				■			■							■				3	C
16	Translation from 2D to 3D						■					■						■	3	B
17	Company Emphasis on Design or Engineering					■							■					■	3	A
18	Educational Background of Individual		■					■			■								3	C
19	Western vs Asian approach of working		■								■					■			3	C
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	-

Observation

Following the interviews, observations were conducted to obtain detailed information by being close to the field of study. The use of observations is advantageous as it allows the researcher to examine interaction taking place between engineering designers and industrial designers in their natural working environment and to record potential barriers that might have occurred. The observations took place through a commercial design project over 2 consecutive weeks and involved the design of a consumer product with an industrial designer and an engineering designer working together. The observation was conducted at a design consultancy within its normal work environment and took place from the beginning of the project (design briefing) to the embodiment stage (3D CAD modelling). As video and voice recordings were not allowed due to project confidentiality, note taking was used as it allowed conversations to be recorded and enabled first-hand accounts of the interaction to be documented. Reliability was achieved by cross-checking records during breaks to minimise work disruption. Other documents, including reports, specification lists and physical or virtual artefacts provided a more complete understanding of the design activities. To obtain a holistic view of issues within the project, observations were undertaken with the project leader, industrial designer and engineering designer.

The observations identified that formal and informal meetings were extremely valuable in enhancing collaboration. Co-location was an important factor since both industrial designers and engineering designers were located close to each other and had significant interaction when compared to other departments who were on a different floor in the building. The observations recorded different working approaches in which engineering designers focused on technical properties and cost whereas industrial designers explored on form and expression. In addition, the lack of a common language in design representations caused miscommunication where certain words were interpreted incorrectly. For example, the engineers had intended simple sketches yet the designers interpreted their task as requiring renderings which the engineers regarded as time-consuming and unnecessary at that stage. The generic term ‘sketch’ did not fully describe the requirements and deliverables for both parties. The observations also found that the loosely rendered sketches from the industrial designers were imprecise and the elliptical shapes drawn in perspective became hard to translate into a 3 dimensional solid in CAD

Outcomes from Interviews and Observations

The interview study identified 3 problem areas in collaborative design which related to conflicts in values and principles. The first, conflicts in values and principles, related to the fact that engineering designers worked systematically based on quantified solutions. In contrast, industrial designers favoured an open-ended approach and used open solutions. The second, differences in design representations, noted that engineering designers often used technical terms and facts that included calculations, technical information and specifications; whereas industrial designers used freehand sketches and drawings to communicate ideas. The third, differences in education, was due to the fact that engineering designers were taught to employ systematic problem solving and to justify solutions with facts. In contrast, industrial designers were taught to solve problems intuitively, rarely relying on quantified data. Due to differences in their educational background, both professions had different specialisations, approaches and expectations.

In addition, the observations revealed the significance of formal and informal meetings; the importance of co-located members; and the issue of having different interpretations of design representation terminology. Of these, the problem area of design representations was found to be highly significant in both interviews and observations and a decision was made to conduct a further investigation.

Phase 2: Investigating the Use of Design Representations

Phase explored the nature of design representations, generated a taxonomy, and collected data on when they were used and for what types of information.

The Nature of Design Representations

The problematic nature of the use of design representations during product development necessitated an in-depth examination of their nature and function during product development.

Design representations can be expressed through language, graphic or artefacts (Goel 1995; Goldschmidt, 1997) and they refer to models of the object being symbolised (Palmer, 1987). During the early stages of product development, representations such as sketches tend to be quick produced and are relatively unstructured. As the design develops, more controlled methods such as drawings and models tend to be employed. Leonard-Barton (1991) noted that the progression of having more information embedded within a representation enhances the understanding of the design. For the practicing designer, sketches support visualisation, communication and information storage (Tang, 1991); externalising ideas (Larkin and Simon, 1987); thinking (Suwa et al, 1998); verification of decisions (Herbert, 1993); and allow a range of interpretations for a design solution (Scrivener, 2000).

While many forms of design representations are available, sketching is seen as being central during the early stages of product development. Goel (1995) sees sketches as the first step of the design process to externalise and visualise ideas at an individual level. At the next stage, representations are used to communicate with others and include presentation drawings and physical models. In the later stages, detailed technical drawings and prototypes are used to communicate detail (Goldschmidt, 1992). In comparing the differences between the representations favoured by industrial designers and engineering designers, Veveris (1994) observed that engineering designers used models associated with engineering principles, functional mechanisms, production issues; whereas industrial designers applied representations related to appearance and usability. Despite various attempts to classify representations (Tjalve *et al*. 1979; Ullman, 1988; Tovey, 1989; Evans, 1992; Goldschmidt, 1992; Veveris, 1994; Kavakli *et al*., 1998; Cross, 1999; Do *et al*., 2000; Otto and Wood, 2001; Cain, 2005; Olofsson and Sjölén 2005; Pavel 2005; Pipes 2007; Eissen and Steur 2008), they are largely incomplete or do not incorporate both industrial design and engineering design representations. In addition, researchers have noted problems with their use when symbolic elements become unclear. The more incomplete or vague a representation is, the greater and wider the perceptual interpretation space becomes. Despite such drawbacks, ambiguous representations allow for creativity and the generation of open-ended solutions (Rodriguez 1992, Ehrlenspiel and Dylla 1993, Fish 1996). They enable things to be seen in different ways that in turn produces new designs and allows flexibility in terms of design attributes.

Although ambiguous representations possess benefits, their ill-defined nature makes it difficult for engineering designers to comprehend and recognise how they work in relation to a product's technical parameters (Saddler, 2001). It may be difficult for a viewer other than the originator to understand the embodied meaning, context or scale (McGown, et al., 1998). The need for accurate and effective representations has been shown by Stacey and Eckert (2003) who provided an example of confusing sketches used in the knitwear industry. They cited that although the lines of a garment sketch were intended to describe the structure pattern, they could be misinterpreted as being stripes on the fabric.

Taxonomy of Design Representations

Following a comprehensive literature review to identify the key design representations used during product development and the information they were used to communicate, a taxonomy was generated that categorised 35 design representations as sketches, drawings, models and prototypes. Eighteen types of information that the design representations were used to communicate were also identified, being categorised under the headings of 'Design Information' and 'Technical Information'. The categories can be seen in Table 3.

Table 3: Categories of sketch, drawing, model, prototype and categories of design information and technical information

Sketches	Idea Sketch Study Sketch Referential Sketch Memory Sketch Coded Sketch	Information Sketch Renderings Inspiration Sketch Prescriptive Sketch
Drawings	Concept Drawings Presentation Drawings Scenario & Storyboard Diagram Single-View Drawing	Multi-View Drawing General Arrangement Drawing Technical Drawing Technical Illustration
Models	3D Sketch Model Design Development Model Appearance Model Functional Concept Model	Concept of Operation Model Production Concept Model Assembly Concept Model Service Concept Model
Prototypes	Appearance Prototype Alpha Prototype Beta Prototype Pre-Production Prototype Experimental Prototype	System Prototype Final Hardware Prototype Tooling Prototype Off-Tool Prototype

Design Information	Design Intent Form & Detail Visual Character Usability and Operation Scenario of Use	Single Views Multi Views Areas of Concern Texture & Surface Finish Colour
Technical Information	Dimensions Construction Assembly Components	Mechanism Part & Section Profile Lines Exploded Views Material

Data Collection on the Use of Design Representations

The taxonomy and categories of information were translated into matrices to use as research instruments. The first matrix was used to appraise the categories of the taxonomy and collect data on when the representations were used. The interview structure and process was identical to that of the first stage of interviews and involved 27 participants of which there were 13 industrial designers, 10 engineering designers and 4 project managers. The results indicated that industrial designers to employ sketches and engineering designers prototypes. Whilst engineering designers did sketch, this tended to be during concept generations but industrial designers employed this during the entire process. The second matrix (see Figure 1) investigated the types of information that the design representations were used to communicate.

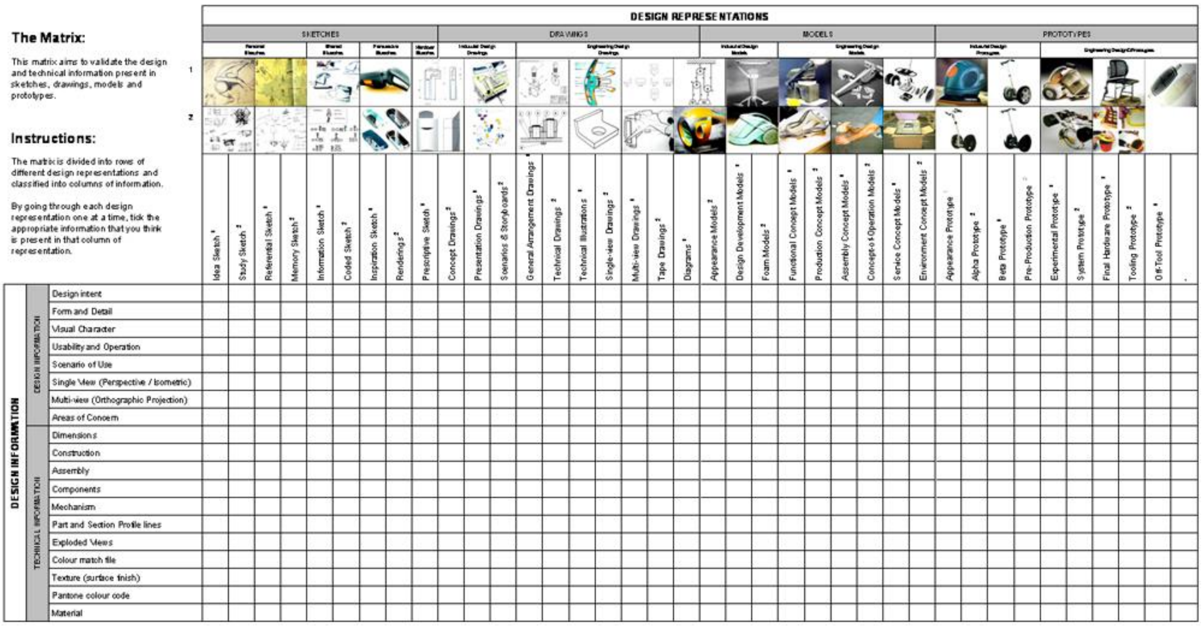

Fig 1: Research instrument to collect data on the types of design information communicated by design representations

The findings from the second matrix-based survey indicated that sketches, drawings and models provided a balanced range of design and technical information, with prototypes focusing on technical information. It was also apparent that design information was more commonly used by industrial designers than engineering designers. Conversely, technical information was more commonly used by engineering designers.

Phase 3: Development of Design Tool

Having defined a taxonomy of design representations and collected data to identify the different way in which industrial designers and engineering designers, Phase 3 translated this knowledge framework in to a useable design tool. For the development of the design tool, several factors were used to determine the tool specification. According to Saddler (2001), the industrial design profession has representations that are ill-defined, imprecise and lack in communicative power. In addition, communication could be improved by having a common understanding of shared definitions (Matthew, 1997). Therefore, the primary feature of the design tool was to clarify the terminology of design representations and to act as an effective means of communicating these shared definitions. To meet this requirement, several physical formats were developed, including matrices, flowcharts, wheel diagrams and Rolodex systems. Digital formats were also considered but this meant that users would need to have constant access to a computer and it would be impractical to carry a laptop at all times. While personal digital assistants, tablets or smart phones presented more portable options, the dissimilar operating systems, short battery life and small screens would create additional problems for information retrieval. In addition, Wi-Fi or internet-based tools would be limited to subscribers or connectivity.

Following an appraisal by the authors, a physical card format was selected for portability and immediate interaction between users. The aim was for the cards to be used by industrial designers and engineering designers as a portable tool that could be carried around as a reference guide or kept as an office resource or learning tool.

The design was undertaken by the researchers and, after numerous iterations, the knowledge framework was translated into two sets of 57 cards each. Both sets of cards included an identical taxonomy but differed in that there was a red set for industrial designers (with information on when this group used the design representations in the taxonomy and for what types of information) and a blue set with similar information dedicated for engineering designers. The principle behind the cards was to standardise language and demonstrate differences in the use of design representations by each group. Each pack comprised 4 cards describing the 4 design stages of product development (Set 1); 10 design information cards plus 8 technical information cards (Set 2); and 35 design representations (Set 3) of the taxonomy. Cards for an Idea Sketch in the taxonomy section can be seen in Figure 2, with the bar graphs indicating what this was typically used for and when, with the industrial designer card being red and engineering designer blue.

Fig 2: Idea Sketch cards for design tool

Appraisal

The design tool, this was appraised through a pilot study that involved interviews with 10 design practitioners. Feedback indicated that a numerical referencing system would support faster access to information and a larger card format (ISO B8 size of 62×88 mm) would improve readability. Other improvements include a simplified layout with less text and larger images. These changes were implemented and the background redesigned to reduce the visual clutter. The revised design for is shown for the entire Sketches section of the taxonomy in Figure 3.

Fig 3: Revised version of the cards for the Sketches section of the taxonomy

Validation

Having integrated several revisions, validation was undertaken through semi-structured interviews with final year industrial design (x4) and engineering design (x14) undergraduates who had worked together on an industrial project; experienced practitioners (x43); and an observation study (x1) to identify the contribution when the card were used during the design of a consumer product in an industrial design consultancy.

In the student interviews, all industrial design students and 92.9% of the engineering design students provided 'good' and 'excellent' feedback on the physical format of the cards. All industrial design students and 85.5% of engineering design students felt that the tool would provide an enhanced understanding of design representations. 66.7% of industrial design students and 64.3% of the engineering design students felt that the cards would be effective in creating common understanding of design representations. While some students found it relatively difficult to search for the correct card, if a systematic approach was followed this should not have been a problem. A significant finding from the interviews was that all industrial design students and 85.8% of engineering design students felt that the tool would have helped to foster enhanced collaboration.

All 43 of the practitioner participants were presented with identical questions to those of the students. When asked about the physical format, 86.4% of industrial designers and 89.5% of engineering designers gave a good/excellent rating. They also believed that that the tool would provide an enhanced understanding and clearer definition of design representations, with 86.4% of the industrial designers and 89.5% of the engineering designers offering agreement. In terms of the capacity of the cards to create a common understanding of design representations, 86.4% of industrial designers and 84.2 of engineering designers believed that they would achieve this. When asked if the system would foster enhanced collaboration, 68.2% of industrial designers gave a good/excellent rating and 27.3% were neutral. 63.2% of the engineering designers gave a good/excellent rating and 36.8% were neutral. A small number of participants claimed that experienced practitioners did not need these cards.

The observation study involved the design of a consumer product within a consultancy over a 3 week period. Observing how the tool was be used within a commercial context proved to be an extremely useful exercise as the authors could not predict how the tool would be received during practice. The industrial designers, engineering designers and team leader were observed and interviewed at the end of each day. During the observations, it was noted that the cards were useful as a clarification tool during the design process. On commencement of the third week, it became apparent that both industrial designers and engineering designers used identical keywords that had been learnt from the cards, thereby minimising the potential for misunderstanding. For example, the engineering designer started to request a more specific type of representation as opposed to a ‘sketch’ as a generic term which enabled more precise and relevant representations to be delivered. Similarly, when there was a need for a specific type of technical information, the industrial designer would refer to the cards to find the exact design representation that was required. The findings from the observations reinforced results from the interviews and provided further evidence of the potential for the tool to foster collaboration in a multi-disciplinary environment.

The validation indicated that most participants gave an excellent and good rating for the design tool although it must be acknowledged that the sample size was limited to 65 participants.

Phase 4: Dissemination and Impact

The overwhelmingly positive response to the CoLab tool indicated the contribution and value of the cards. As academic research, it would have been possible for the researchers to have concluded their work at the validation stage but a decision was made to maximize impact through a process of dissemination.

CoLab

Despite making contact with numerous commercial and non-profit organisations who saw value in the CoLab tool, the relatively expensive production costs for 114 double sided playing card-size cards was prohibitively high. Whilst the researchers had made a conscious and informed decision to create a physical design tool, there was a fundamental change in direction when an opportunity arose to translate CoLab into a web based tool with the support of the UK’s Royal Academy of Engineering.

With funding from the National HE STEM Programme, the data on when design representations were used and for what types of information was translated into a database driven website with functionality that was almost identical to that of the physical CoLab cards. The screen for the Embodiment Design section of the web-based version of CoLab can be seen in Figure 4.

The orange tab at the bottom of the card indicates that it is one of the four Design Stages cards and the white background shows that Embodiment Design has been selected. The red card shows that the most popular design representation used by industrial designers during this stage was the Mulit-view Drawing (70%) and the blue card that the most popular for engineering designers was the Technical Drawing (70%). An additional level of functionality enables the user to click on the wording for the Design Representation and this then reveals full details on that particular card. For example, Figure 5 shows the Idea Sketch card from the Design Representations section (i.e. the taxonomy).

Fig 4: Design Stages cards showing information for Embodiment Design

Fig 5: Idea Sketch card from the Design Representations section

The purple tab at the bottom of the card indicates that this is from the Sketches section of the Design Representations. The red card indicates that Idea Sketches were mainly used by industrial designers (90%) to provide information on Design Intent and the blue card by engineering designers (50%) to provide information on Components. Design Intent is categorized as a type of Design Information and, again, by clicking on the wording reveals this card which has a green tab (Figure 6).

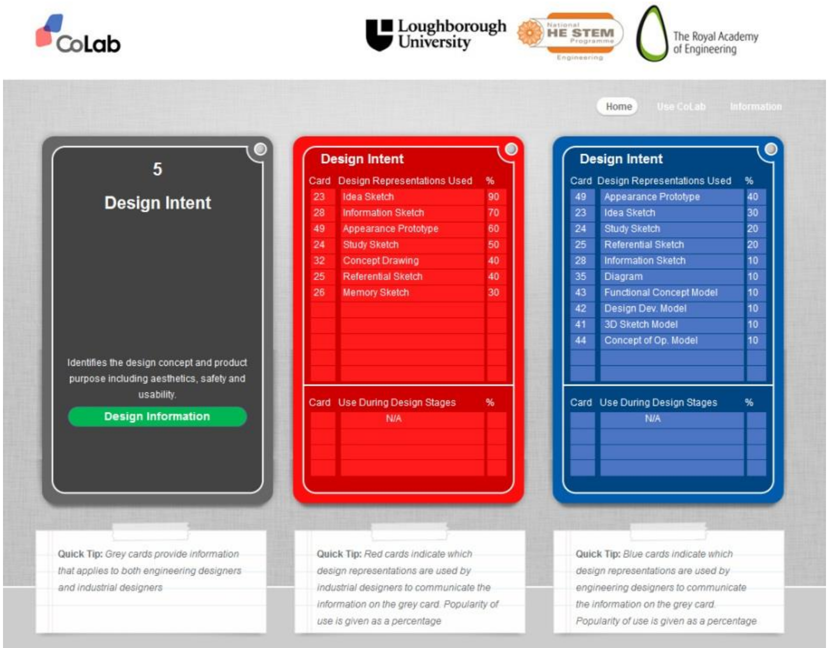

Fig 6: Design Intent card from the Design Information section

Components is categorized as a type of Technical Information and clicking on the wording reveals this card which has a yellow tab (Figure 7).

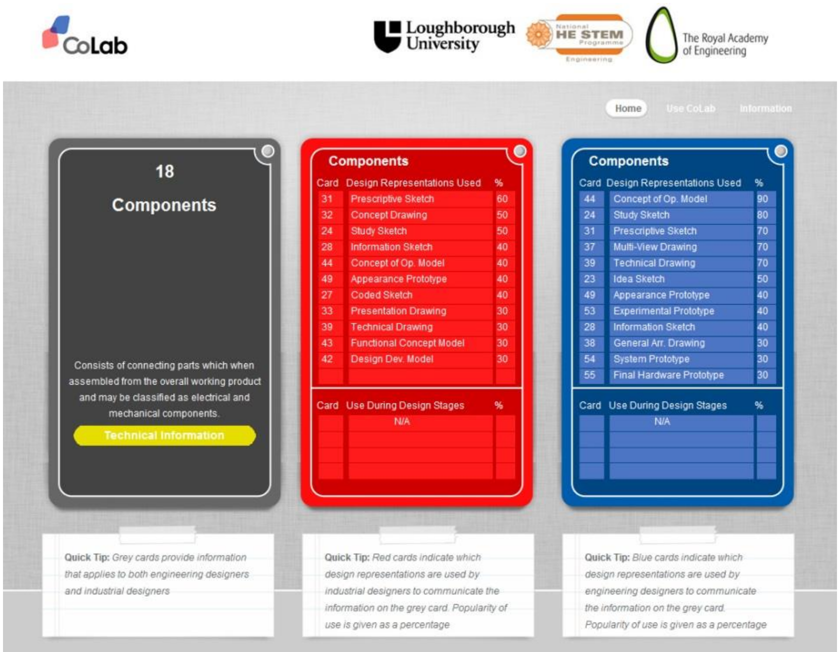

Fig 7: Components card from the Technical Information section

The CoLab website is available at www.colab.lboro.ac.uk

iD Cards

As a member of the Industrial Designers Society of America (IDSA), one of the researchers had presented the development of the tool at several of their International Conferences. Following significant interest, particularly for the taxonomy, information on the use of design representations by industrial designers only was translated by two of the researchers into a fold-out tool using the Z Card printing process. This enabled the folds created by the 48 credit card-sized panels to replicate the card-based approach (see Figure 8).

Fig 8: iD Cards

The revised tool, called iD Cards, was approved by the Board of Directors of the IDSA in January 2011 and 5000 sets ordered for distribution to their practitioner, educator and student members. Further validation of the contribution of the iD Cards was received when they became a finalist in the 2011 International Design Excellence Awards. The information provided in the iD Cards groups representations as Sketches, Drawings, Models and Prototypes, indicating when an individual card is used (yellow tab active) and for what type of information (red tab active for a type of Design Information, blue tab active for a type of Technical Information). Details in the type of information is provided on a separate panel as are instructions on use. The two sides of the folded-out iD Cards can be seen in Figure 9 and 10.

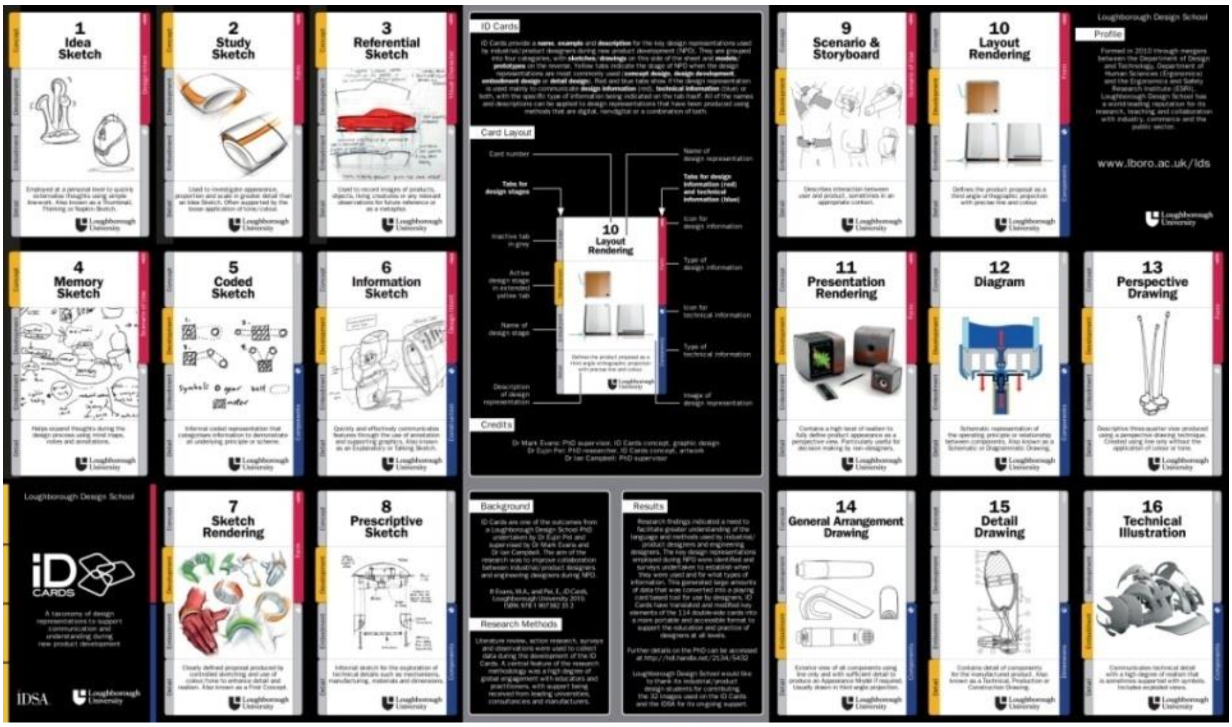

Fig 9: Folded-out front face of iD Cards

Fig 10: Folded-out rear face of iD Cards

Despite the researchers wish to create a physical design tool, on-going demand necessitated the conversion of the iD Cards into a pdf that was made available on the Design Practice Research Group web site at http://www.lboro.ac.uk/departments/lds/research/groups/design-practice/

Conclusions

Design representations are an integral component of product development as they support innovation through the externalization, manipulation and communication of design. The fact that design representation, collaboration and communication are closely linked means that the use of CoLab and iD Cards can contribute to professional practice by presenting a language platform to standardise vocabulary, thereby facilitating social networks and enhancing understanding between stakeholders. The context where the tools can be used is not limited to industrial designers and engineering designers but has the potential for use by other stakeholders, including marketing and production engineering. Additionally, the tool has an application as a teaching and learning tool in design education.

Whilst the formalisation embodied in the tool might be seen as introducing rules and procedures which, at times may have a negative impact (Burns and Stalker, 1961), the authors believe that a focused system can minimise misinterpretation and lead to more accurate communication. By including key design and technical information, the tool serves as a decision-making guide and helps identify representations used during design stages. It also allows industrial designers and engineering designers to be aware of each others' working practice and aids the coordination of actions, task management and the anticipation of actions by others (Gutwin and Greenberg, 1996). Through the use of the CoLab and iD Cards, inter-disciplinary teams are able to develop a shared language to communicate effectively. By simplifying processes and communication, barriers to interaction are reduced, operations are quickened and parallel processing achieved. Users are able to eliminate unnecessary design representations, saving time, accelerating product development.

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