ADOPTION OF A SYSTEMATIC DESIGN PROCESS: A STUDY OF COGNITIVE AND SOCIAL INFLUENCES ON DESIGN

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ABSTRACT
This paper presents an ethnographic case study of an engineering design team during the development and implementation of a systematic design process. Prior to this study the team had used only ad-hoc and informal design strategies. The team was observed for 12 months after implementation of the new process, during which time two subsequent versions of the design process were developed and released in response to observations and team feedback. The findings of this study highlight the way in which cognitive and social factors may have a strong influence on the design process in teams, and should therefore be given greater consideration in the future development of design methods and processes as well as in design education.

Keywords: Design methods, design cognition, engineering design teams, ethnography, social process

1. INTRODUCTION
Much of the empirical design research conducted over the last few decades has focused on formal laboratory-based methods, such as protocol analysis, and/or use of design students as research subjects (e.g. [1], [2], [3]). A small number of industry based studies have also been undertaken (e.g. [4], [5], [6]) but over timescales of only weeks or months, and involved external researchers from academia. This research, though useful and enlightening in many respects, does not provide the whole picture. There still exists a divide between academic design theory, and the reality of design practice in industry. More research is needed out in the field, over longer timescales, and conducted by practicing designers immersed in the context of study. This may lead to an improved understanding of why the use of formal design methods is not more widespread, how appropriate these methods are in an industry context, and how design is really done in the field. For instance, how do the cognitive and social processes involved in design influence design outcomes? How do designers interact in teams? The research presented here begins to explore some of these factors, with the objective of improving design quality within a specific organisation, but also of better informing general design theory and design education. This paper presents the results of an exploratory case study of an industry-based engineering design team, as they adopted a structured design process involving formal design methods, over the course of one year. The decision to implement a more structured design process came after reviewing data from semi-structured interviews conducted with team members prior to the study. A clear theme that emerged from the data was a desire by team members for more structure and accountability in the design process. The research was conducted by a practicing member of the design team, who was a full participant in the use of the new design process. This case study forms the first part of a 4 year ethnographic research project undertaken within this particular design team.
Section 2 of this paper gives an overview of current thinking in design cognition and design methods use in industry. Section 3 describes the context of the particular case study and the research methods used. In section 4 the case study findings are presented, and the paper concludes in section 5 with a final discussion and plans for future research.

2. BACKGROUND

2.1. What is design?
Design draws upon many different disciplines; from the creative arts and physical sciences, to psychology and anthropology. Yet it does not sit comfortably within the paradigms of any. Design is intangible and elusive, defying reduction, analysis, and understanding using the methods and mindsets

of these subjects. Given the vast array of published research, reporting ever evolving perceptions and interpretations of design theory and practice, it is difficult even to pinpoint a universal definition of design. Buchanan [7] suggests that a common theme can be found running throughout the landscape of design. This he refers to as “the conception and planning of the artificial”. Another unifying attribute of design, or more specifically of design problems, put forward by the mathematician and designer Horst Rittel is the concept of ‘wickedness’. Rittel [8] proposed that ‘wicked’ problems are a "class of social system problems which are ill-formulated, where the information is confusing, where there are many clients and decision makers with conflicting values, and where the ramifications in the whole system are thoroughly confusing”. This wicked problems approach is an antidote to the conventional linear model of the design process previously favoured by many design theorists. This linear process is characterised by two distinct phases: problem definition (analytic) and problem solution (synthetic), and its appeal lies in the systematic and objective precision with which it treats design problems. It is predictable, repeatable and free from the subjectivity of individual designers. This approach assumes however that design problems are fundamentally determinate in nature and have measurable conditions and limits. Rittel argues that most problems addressed by designers are in fact wicked problems, characterised by indeterminacy and without definitive conditions or limits. This is illustrated by Rittel’s ten properties of wicked problems:

1. Wicked problems have no definitive formulation, but every formulation of a wicked problem corresponds to the formulation of a solution.
2. Wicked problems have no stopping rules.
3. Solutions to wicked problems cannot be true or false, only good or bad.
4. In solving wicked problems there is no exhaustive list of admissible operations.
5. For every wicked problem there is always more than one possible explanation.
6. Every wicked problem is a symptom of another higher level problem.
7. No formulation and solution of a wicked problem has a definitive test.
8. Solving a wicked problem is a ‘one shot’ operation, with no room for trial and error.
9. Every wicked problem is unique.
10. The wicked problem solver is fully responsible for their actions.

Rittel concludes that the variety of characteristics involved in wicked problems, mean they cannot be solved using a structured, linear approach. This is illustrated in a study by Eisentraut [9] that found individual yet stable styles of problem-solving appeared when designers were confronted with complex problems. Eisentraut suggested that individual problem-solving behaviour may be essential in optimising particular design processes. He also suggested that there is not ‘the one right way’ that is adequate in all problem situations, and this should be reflected in design education.

2.2. Design cognition

Research aimed at trying to understand the complicated actions and behaviours of designers has been carried out into many areas of design, primarily using theory from the field of cognitive psychology; the study of mental information processing and the role it plays in emotion and behaviour. Several internal ‘cognitive’ processes have been identified which we use to assess our surroundings and make appropriate decisions [10]: attention, perception, learning, remembering, speaking, problem-solving, reasoning, and thinking. Each of these processes can be seen to occur at some stage within the design process, so research into this area is of significant importance. There has been a steady increase in empirical research studies of design cognition since the work done by Eastman [11] involving studies of architects. However, the total amount of research in this area is not large, and the results are varied. Studies tend to involve small numbers of subjects, and few studies have been repeated in order to validate findings. In his review paper Cross [12] separates his findings on patterns and issues in design cognition into three distinct categories: problem formulation, solution generation, and process strategies. A further category of ‘team design’ has been added here. These topics are discussed below.

Problem formulation - Research seems to suggest that it is appropriate that designers do not spend too much time on initial problem definition. Some studies (e.g. [13]) have indicated that focusing too much effort on problem definition ultimately leads to inadequate design outcomes, through solution avoidance. Better quality design comes from appropriate ‘problem scoping’ where small amounts of information about the problem are sought and digested at intervals, interspersed with solution conjecture. Overall the research indicates that designers are solution-led, not problem-led, or in other words solution evaluation is more important than problem analysis. Research has also highlighted the concept of ‘problem framing’, where a designer actively constructs a particular view of the problem, mentally defining the boundaries, and uses it to direct the search for solutions. Several studies have looked at problem framing in individuals (e.g. [14], [15]). The results suggest that the most experienced and successful designers are skilled at appropriate problem framing. Several studies have also identified that designers quickly jump to making solution conjectures, therefore exploring and defining the problem and solution together. This also appears to increase with experience. Experienced designers also tend to use more ‘generative’ reasoning, whilst novice designers rely on deductive reasoning. . The concept of ‘co-evolution’ of problem and solution has also been proposed [16], where a designer’s thoughts alternate between problem and solution, enabling partial structuring of the two ‘spaces’. Cross suggests that designing is an “‘appositional’ search for a matching problem-solution pair, rather than a propositional argument from problem to solution.”

Solution generation **-** Solution-focused behaviour seems generally appropriate in the context of designing. However, this behaviour is also associated with some less desirable attributes. First suggested by Jansson and Smith [17], ‘fixation’ can be both a positive and a negative attribute of design behaviour. Designers can become fixated on a previous or similar solution, or solution principle. This behaviour tends to result in incremental or routine design. However, when fixation is channeled appropriately, it can result in highly creative, innovative design. In the case of the latter it is thought that the designer is able to shift fixation away from a specific solution, or solution principle, and onto the problem frame instead [18]. Purcell & Gero [19] compared senior students in mechanical engineering and in industrial design with results suggesting that mechanical engineers were far more susceptible to fixation than industrial designers, however, Purcell and Gero concluded that industrial designers simply ‘fixated on being different’. Another form of fixation is ‘attachment to concepts’, where designers are reluctant to abandon early concepts despite mounting evidence that a better solution is needed [20]. Design theorists generally advocate generating a wide range of alternative solution concepts, but this rarely happens in practice. Research shows that generating a very wide range of alternatives may not be a good thing, and that generation of a relatively limited number of alternatives may be the most appropriate strategy. Results from a protocol study of engineering designers [2] suggest that generating a very small, or very large, number of concepts were both unsuccessful strategies.

Process strategy **-** Design in practice still tends to be a fairly ad-hoc and unsystematic affair, despite the concerted efforts of many theorists over the decades to implement methodical, systematic procedures. The reality of practice is that designers remain wary of systematic procedures that, largely, still have to prove their value in industry. Following a *reasonably* structured process does seem to lead to greater design success [21]. However, rigid, over-structured approaches do not appear successful. Fricke also studied a number of mechanical engineers, of varying experience and varying education in systematic design process. He found that designers following a ‘flexible-methodical procedure’ tended to produce better quality designs. The key to this flexible approach seems to be a sophisticated understanding of process strategy and its control. Designers also frequently display opportunistic behaviour, where they are seen to spontaneously deviate from the systematic process in order to follow an unexpected lead. Studies suggest that we should not equate ‘opportunistic’ with ‘unprincipled’ behaviour in design, but that opportunism should be seen as a characteristic of expert design behaviour. Visser [22] proposed that the excessive ‘cognitive cost’ of maintaining a structured approach was the major reason for this behaviour. This cognitive cost associated with principled, structured behaviour may sometimes be unsustainable, or unjustifiable in relation to the quality of outcome. It has been noticed in some studies (e.g. [23], [13]) that creative, quality design behaviour appears to be associated with frequent switching of types of cognitive activity. This observation is difficult to explain, but may be related to the ‘co-evolution’ of problem and solution. The behaviour of expert designers seems to frequently contradict theory in relation to problem-solving expertise. Empirical studies of design activity (e.g. [18], [24]) have frequently found ‘intuitive’ features of design behaviour to be the most effective and appropriate. Whereas some prescriptive models and processes derived from design theory are fundamentally counter-intuitive to design behaviour.

Team design **-** A study by Stempfle and Badke-Schaub [25], involving three student design teams showed that each team evolved a completely different design strategy in order to solve a set task. The study also indicated that the teams did not follow systematic design steps at any stage of the design process. Stempfle and Badke-Schaub proposed that it is a natural human characteristic to use 'quick and dirty' decision-making methods in favour of more systematic approaches, in order to reduce the complexity of the task in terms of cognitive effort and time required. In another study Cross and Clayburn Cross [26] suggest that team work is a social process, and that "social interactions, roles and relationships cannot be ignored in the analysis of design activity performed by teams". They state that many aspects of team design activity are influenced by social factors. For example in how a team may switch between planned and unplanned activities, the way personal commitments to particular concepts lead to social actions, and in the socially adept ways in which conflicts are resolved or avoided. They conclude that the results of their study are relevant to the analysis of design activity, and to the design methodology of teamwork. In his ethnographic study of design teams Bucciarelli [4] also concluded that design should be considered as a social process. The engineering domain in particular has tended to treat the design process as a technical process. More recently design has also been considered as a cognitive process, but only a few studies have paid attention to designing as a social process. Cross and Clayburn Cross conclude that design methodology needs to address design in a more holistic way, as an integration of all three of these processes.

2.3. Design methods in Industry

Although a plethora of theoretically effective design methods have been developed in academia over the years, it has been well documented in the literature that awareness and uptake of these methods in industry has been limited (e.g. [27], [28], [29], [30], [31]). The literature also suggests a variety of reasons for this. For example, it has been noted that design methods are usually developed in academic isolation, away from practicing engineers, and tested only on students or in controlled laboratory environments. As a consequence the full complexity of using such methods in an industry setting is not understood, which often makes effective implementation in practice difficult. The terminology and vocabulary associated with the methods is often impenetrable to non-academic engineers and often at odds with the familiar language of the particular organisation. Methods are also often inappropriate for the purpose they are used and ultimately only stifle creativity, slow down the design process and generate unnecessary documentation. In cases where methods may actually be of use practicing engineers lack the knowledge and confidence in using them effectively, they may also be reluctant to take a risk over using more familiar trusted approaches. There is also likely to be a delay between implementation of the methods and any tangible improvements in design outcomes, potentially leading to premature rejection of new methods. Gunther and Ehrlenspiel [32] suggest that academia also has too narrow a focus when it comes to developing methods, that they are only concerned with 'developing products that meet an optimal quality', when in fact methods that support 'design in the minimum time with minimum effort' are more appropriate for much of industry.

3. RESEARCH CONTEXT AND METHOD

3.1. Case study context

The case study was undertaken within a small UK sustainable energy consultancy employing less than 50 people. The particular unit of analysis was the engineering design team, consisting of 9 design engineers (including the author), of which 7 were men and 2 were women. The average age was approximately 30 years and all members of the team were based within the same office. During the course of the case study one member of the team left and two new members joined, including a team manager. In general members of the team can be characterised as well-educated, motivated, creative, and high achieving. The primary work of the team is engineering design of innovative marine energy technology for client developers. The case study focused on one particular project, the design of a pre-commercial tidal stream energy device. The 12 month time-scale of this initial study spanned the concept and preliminary design stages of the product lifecycle.

3.2. Method

Ethnography is a research technique borrowed from anthropology. It involves immersion of the researcher in the particular culture of the subjects being studied, in order to generate a description and interpretation of that culture and its social structure. Bucciarelli [4] undertook two ethnographic studies with different engineering design firms, using participant observation as the primary research method. The four key aspects that identified it as an ethnographic study were:

- All that went on within the firms was potentially designing.
- Every activity carried out within the design firms was potentially an important design act.
- Of the many members of the firms, all were potentially effective players in the design process.
- All members of the firms and their external contacts were potential contributors.

Baird et al. [5] also used an ethnographic approach in a study of design teams at Rolls Royce. The aim was to better understand the cognitively tacit processes and actions of team work in design. Ball and Ormerod [33] suggest how ethnography can be tailored to the study of realistic design activities. They propose three ways in which applied ethnography differs from pure ethnography: it differs in intensity of observation, is less independent of prior theory, and requires a degree of verifiability or objectivity in interpretation. Ball and Ormerod suggest that any study adopting an ethnographic approach should make explicit the particular adaptation from pure ethnography, in addition to any underlying assumptions or goals. Ethnography has been used as the primary research method in this study, but with several specific adaptations. Firstly, the focus of study is quite specific i.e. how the design team responds to the introduction of a systematic design process based on prescriptive design theory. Secondly, the new process was developed and implemented by the author, who had a role as researcher, team member, process champion, and trainer, and therefore influenced the context of study considerably. Thirdly, analysis of the data has been carried out with prior theory in mind (as outlined in section 2). It is felt that these adaptations are appropriate given the nature of the study.

A key aspect of an ethnographical study, according to Robson [34], is the long time scales involved and the fact that subjects are studied in their natural setting. Robson however, claims that undertaking true ethnographic studies, over a period of years, is highly unrealistic in design cognition studies. Most of these studies have attempted to conserve the core principles of the ethnographic process, but within times scales of weeks. The initial case study presented here (12 months), in conjunction with the research ongoing as a continuation of this study (3 years), attempts to stay true to the original ethnographic approach. Criticisms of ethnography as a research method in design focus on the lack of objective data relating to the cognitive processes of participants. Conclusions are based purely on the interpretations of the researcher, raising questions about the validity of the findings. The ethnographic approach appears to be very subjective and differs to a great extent between studies. However, it does provide a richness of data and context that simply cannot be obtained using protocol analysis or other formal research methods. It therefore has an important place in design research.

3.2.1. Implementing a systematic design process

Prior to the case study semi-structured interviews were conducted with members of the design team. It was anticipated that the team was about to undergo significant change as the marine energy area of the business was expanded, meaning additional recruitment and more projects. The key questions this raised were; ‘how does the team currently go about design?’, ‘why do they do it this way?’ and ‘how can design be improved for the future?’ The interviews also served as a means to better understand the team culture and how individuals perceived team strengths and weaknesses. A key theme that came out of the interviews was a desire for more structure in the design process (see section 4 for data analysis). This prompted the development of a new systematic design process based on prescriptive design theory (e.g. [35]). Design methods contained in the new design process included: requirements analysis, functional analysis, QFD, brainstorming, morphological analysis, and fault tree analysis. The process also outlined formal design reviews, design freeze and change control points. This systematic design process will be referred to here as the SDP. The initial SDP (SDP1) was an eight stage process, broken down into numerous subtasks, outlined in a 60 page manual. This was used for the first 4 months of the study before a revised version was developed. This was a much simplified 3 stage process outlined in a 20 page manual, SDP2. Ultimately this was further simplified to a 2 stage process, SDP3, and used for the final two months of the study. Implementation of the SDP was in-line with that advised by Booker [31] in his review paper on methods use in industry. For example the SDP had the full endorsement of the management as well as the project client, it was developed with consideration of current company and team culture, it had a ‘champion’ in the form of the author, and all team members had training in use of the SDP.

3.2.2. Data collection

- *Semi-structured interviews* – These were conducted prior to development and implementation of the SDP. Each member of the team was interviewed separately, each being asked the same set of open-ended questions relating to design practice within the company. Each participant was also asked what they perceived the current strengths and weakness of the team to be in terms of producing quality design. The interviews ranged in length from 40 mins to 1 hour and participants were free to raise any issues they wished during that time. Each interview was recorded and later transcribed. The purpose of the interviews was to assess potential for improvement in the way the team went about design. The results were used to inform development of SDP1.
- *Focus group* – Four months into the study a focus group was held with the team in order to assess progress in using the SDP. Participants were asked to comment on what they felt had gone well, what had not, and what they felt what could be improved. The session lasted approximately one hour, was recorded and later transcribed. The results were used to inform development of SDP2.
- *Participant observation* - Throughout the study data relating to the daily design activities of the team were collected through participant observation, a data collection method in which 'the researcher attempts to participate fully in the activities of subjects and thus becomes a member of their group' (Gill & Johnson, 1993). During the study the author adopted the role of *observer as participant*, thereby fully participating in the action without concealing the research purpose from the study subjects. This was in order to gain the most intimate understanding of the study context, whilst avoiding any possible issues of ethics. It is possible that some team members may have adapted their behaviour in response to being under observation, particularly in the beginning, but given the long duration of the study it seems unlikely to have had a large impact overall.
- *Document review* - The SDP was designed to generate specific documentation for each part of the product system at each stage in the lifecycle, though the format of this documentation evolved with each version of the SDP. These included a 'design definition', and 'design solution' document for each subsystem. These documents were interrogated for completeness, relevance, and consistency as part of the overall data analysis of the study.

4. FINDINGS

4.1. Interviews

The interview transcripts were analysed and three key themes were identified; lack of knowledge relating to design theory, desire for more structure, and informal team and company culture. These themes are discussed below.

- *Lack of knowledge relating to design theory* – The majority of engineers interviewed did not appear to understand the concepts of 'design method' or 'design process'. When asked to "describe the design process you would normally follow", the response was often a description of ad-hoc, piecemeal, unsystematic work, involving no recognisable methods. There was also confusion between what constituted a design standard (e.g. a BS standard), a quality management system, and a design process. There was no evidence of formal problem formulation, such as requirements setting, at the outset (or during) a project. There was also no evidence of a top-down perspective of the product system. Design seemed based on fairly arbitrary criteria and design of subsystems was sequential, meaning that design of one subsystem set the constraints of the next and so on. Problems or mistakes were therefore carried through the design from one subsystem to the next. There was also no evidence of formal design reviews, design freeze, or change control.
- *Desire for more structure* – It was apparent that team members felt that many of the problems encountered in previous projects were due to a lack of formal structure or process relating to design. Problems were often not anticipated in advance and re-design was a common feature, particularly in the final project stages. Lack of process structure and formal requirements setting led to confusion and often disagreement with the client. Team members were often unaware of the work being undertaken by others, both in the team and by the client. This led to some replication of work. Team members expressed a desire for a more structured design process, and a single point of authority, in the form of a design team manager.
- *Informal company and team culture* – Most team members considered the greatest strength of the organisation, and the design team, to be its people. The design engineers felt that they were highly

motivated, creative, independent thinkers that worked well together. It was clear that team members valued these attributes and were concerned that any formal design process should not de-motivate, inhibit creativity, or destroy the informal culture of the team.

4.2. Focus group

During the focus group the team gave feedback on using SDP1. In general they felt that there was value in using a systematic design process, and that there had been a need for one, but the SDP1 process was too lengthy, time-consuming, complicated, unnecessary in the level of detail, and not compatible with the way project partners or the client worked. The manual was also written in language that was difficult to understand. SDP2 was developed in response to this feedback.

4.3. Observations

Table 1. Observations categorized by nature of factor influencing design

Factor	Observations
Cognitive	• *Formal methods more time consuming than informal methods* – This was a major issue at the start of the study, when SDP1 was being used. The time demands of using the methods were unsustainable. With each of the two successive versions the situation improved. However, when ever time has been a limiting factor, the formal methods have been dropped in favour of informal ones. • *Early attachment to concepts* – Engineers tended to commit early to particular design solutions, often the first or only solution proposed. This fixation made some team members reluctant to use the formal methods, they felt they had already found a solution and did not need to waste time 'ticking boxes'. • *Retrospective method use* - Designing was generally done first using informal strategies, and then the formal method was 'fixed' to give the desired result. This may explain why the methods were particularly time consuming, the designers were essentially doing the work twice. This was later used as 'evidence' that the methods were not useful. • *Methods not used as prescribed* – Engineers frequently did not to read the SDP manual on how to use the methods, but reworked the output of the method from other parts of the product system. Or they guessed at how to use them, often incorrectly, producing meaningless diagrams and data. This was often later used as further evidence that the methods did not work or were not helpful. • *Methods against instinctive designer behaviour* - Team members commented they felt the methods sometimes inhibited creativity and independent thinking. Team members wished to go straight to exploring solutions whereas the early methods required suspending thought until later in the process. One designer pointed out that it was impossible to 'not think' of solutions right from the start; that it was 'human nature'. Team members often felt that the methods could be replaced by common sense.
Social	• *Process champions* - Management endorsed use of the design process but did not ensure that it was being followed. It was left to individuals to choose to use it or not. There were some members of the team who saw more value in the methods and were instrumental in keeping the SDP going, as well as encouraging others to see the value in it. One member in particular became a guinea pig for trialling the methods and each new version of the SDP. He was then able to support other members of the team in using the methods and in selling their value.
Both cognitive and social	• *Confusion about purpose* –At the beginning of the study most team members confused the concept of a systematic design process with that of a quality management system, this was already clear from the interviews. This rapidly evolved into a belief that the new design process was a 'magic bullet' for designing, which then turned to disillusionment once the design process was implemented. • *Inaccessible language* – The language and terminology relating to the methods was unfamiliar to most members of the team. During use of SDP1 this made it almost

	impossible for the engineers to complete the tasks unassisted. A direct result of the language issue was a general mocking of the methods, the language often made them seem absurd. The main purpose of SDP2 was to describe the method steps in a more accessible and familiar language. • *Methods not used at all* – Team members would frequently skip methods in the design process if they felt the method was not relevant. Closer observation of this behaviour often revealed additional contributing factors such as time constraints, fear of using the method, mistrust of the method. • *Lack of trust in the methods* – The team were not always convinced that the methods would produce a better result than could be achieved using informal strategies.

4.4. Documentation

The most immediate finding of the document analysis was how much was missing, both in terms of whole documents, as well as parts of documents. The language used was often inconsistent between documentation for different subsystems, including the document titles, despite guidance on nomenclature in the SDP manual. This confusion may have been, in part, due to evolution in terminology with each version of the SDP, from academic to more informal. Each team member also appeared to have his or her own unique approach to document generation, only including what they felt was relevant, or what they felt they understood. Much of the documentation that was generated was ultimately unhelpful. It was clear that team members were using documentation from other parts of the system as a template for subsequent parts, or subsequent stages in the life-cycle, but altering the content in only a superficial and often unhelpful way.

4.5. Final outcome of the implementation

Despite many teething problems, and some resistance by team members, overall implementation of the systematic design process and its formal methods has been deemed successful by the team and by management. The team intends to continue using the SDP on the tidal stream project in question, and the process is also to be introduced on a new wave energy project of similar scope and scale. Observations and feedback from the team, and from the client, indicate that the SDP has increased the accountability and auditability of the design work throughout the project; it has lead to better communications and relations with the client, and has also increased confidence in the capability of the company to external organisations, such as auditors, technology certifiers, and potential investors. However, it is not clear that the SDP has actually improved the *quality* of design itself.

5. DISCUSSION AND CONCLUSIONS

This paper has presented an ethnographic case study of an engineering design team during the development and implementation of a systematic design process. Interviews were conducted with team members early on and the data identified a desire for more structure in the design process, despite a lack of familiarity with design theory and associated methods. The data also highlighted that the personal qualities of individuals and informal team culture were perceived as significant design strengths. The team were trained in the use of a new systematic design process (SDP) and observed for 12 months as it was used on a new design project. Two subsequent versions of the SDP were developed in response to observations and feedback.

Some of the findings of this study appear to confirm conclusions reached by others reporting in the literature. For example, that designers are naturally solution-led, not problem-led. This was seen often in the behaviour of the design team; engineers were often keen to explore the solution space before fully defining the problem. They felt the SDP and its methods were counter-intuitive in this respect, and intuitive behaviour of experienced designers has previously been shown as more effective than prescribed theory in practice. The theory of ‘co-evolution’ of problem and solution also seems to fit well with design behaviour seen in this study. It would also appear that mechanical design engineers are indeed susceptible to fixation in the form of attachment to concepts; this behaviour was displayed frequently by all members of the team. Previous research has also indicated that following a *reasonably*-structured process does lead to greater design success, but that rigid, over-structured approaches do not appear to be successful. This can also be confirmed by this study, where SDP1 can be considered a rigid over-structured approach and SDP3 a flexible-methodical approach. However, one has to consider what exactly is meant by design success. The SDP lead to successful outcomes for the team, and for the organisation, but these were largely related to the increased accountability of design decisions and improved communication with external parties, including the client. There is no evidence yet that design quality has improved.

What is not covered by previous research is the degree to which cognitive and social factors influence the behavior of designers in practice. Designer behaviour seen in this study was sometimes rational and appropriate in relation to use of the SDP, for example SDP1 was too time consuming and the language inaccessible. The team responded by cutting out what they deemed irrelevant and prioritising work in order to meet deadlines. However, designer behaviour sometimes appeared irrational and counter-productive. For example, the way in which team members would 'fix' certain methods to give desired results, or make little attempt to learn methods - resulting in incorrect use - then claim the methods were not useful or effective. In addition to this the academic language of the methods was often mocked by team members, this had the long-term effect of stigmatizing the SDP. The mocking appears to have stemmed from an underlying fear and mistrust of the methods, of not understanding how to use them, and from fear of being exposed as inadequately skilled. Other apparently unhelpful behaviour was related to minimising cognitive workload, such as using previous documentation as a template for new design work. This could be considered as an example of 'design in the minimum time with minimum effort'. This strategy meant the team members could generate something that 'looked' like good design, but involved limited cognitive effort. Engineers rarely referred back to the SDP manual on how to use the methods, even when this was explicitly suggested. There were some team members who saw more value in the methods and were instrumental in keeping the SDP going, as well as encouraging others to see the value in it. This strong social influencing seems likely to have made the difference between the SDP succeeding and failing.

The findings of this study suggest that prescriptive design theory does not sufficiently account for the realities of design in practice. A designer working in industry is faced with a multitude of demands on his or her time and powers of cognition. Their aim may often be design that is 'fit for purpose', rather than 'optimal' design. A designer is also human, and therefore susceptible to irrational or emotional behaviour, driven by the need for social acceptance. In general, design theory needs to address the design process in a more holistic way; as an integration of technical, cognitive and social processes.

A key outcome of this exploratory study is the development of a new research question for the overall project: 'what are the cognitive and social factors influencing design outcomes and how can they be described and understood?' The next stage of the research will focus more closely on observing and understanding social interactions within the team, and how these interactions may be beneficial or detrimental to the quality of design produced. It is felt that teething issues relating to implementation of the SDP have largely been dealt with, and that a fairly optimal, 'flexible-methodical' process is now in place. This should allow any underlying social factors influencing design to come to the fore.

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