**INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07**
28 - 31 AUGUST 2007, CITE DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE

# CHARACTERISING DESIGN QUESTIONS THAT INVOLVE REASONING

**Aurisicchio M., Bracewell R.H. and Wallace K.M.**
Engineering Design Centre, Department of Engineering, University of Cambridge, Cambridge CB2 1PZ, United Kingdom

## ABSTRACT
The engineering design process requires designers to ask numerous design questions. Product reasoning questions are a subset of design questions closely related to problem solving. Establishing what types of product reasoning question designers ask and how they use these questions in the design process has the potential to develop methods to support designers. This paper presents the results of a study to understand the nature of product reasoning questions. The research is based on rich data sets of questions that were collected from designers working in industry. The analysis of the data led to the development of two categories to characterise the objectives of product reasoning questions and to distinguish them depending on the problem type that they intend to progress.

*Keywords: empirical research, product reasoning questions, problem solving*

## 1 INTRODUCTION
The engineering design process can be viewed as a complex problem solving activity that involves reasoning from a set of needs, requirements and intentions to the form and materials of a product. The design process is also a context-bound activity frequently situated in commercial organisations that have their own practices, structures and social interactions [1]. In this process, engineering designers generate several types of question both working individually and in a team. Finding satisfactory answers to these questions is key to progress designs. An empirical research study to explore the nature of the questions formed while designing found that the timing and the types of question have a direct bearing on design performance [2]. At the same time, another empirical study to research differences between novice and experienced designers found that novice designers frequently do not know what questions to ask [3]. Research to investigate questions has, therefore, the potential to develop methods to: (1) teach novice designers what questions they should ask; and (2) make sure that designers ask the right questions. Overall, little research has been carried out in this area. This paper presents the results of a study to characterise design questions that involve reasoning and are product based. Such questions will be referred to as *product reasoning questions*. In particular, the specific research question that guided this study is: What are the characteristics of product reasoning questions?

## 2 PRODUCT DEVELOPMENT AND REASONING QUESTIONS

### 2.1 Asking questions
A question is a speech act or conscious thought expressing a need related to a design task, whereas an answer is a result related to a design task. Designers are generally graduates in engineering that at school and university are trained to answer questions that others have already answered. They generally learn in the field how to approach and how to find solutions to design problems. Hence, it can be hypothesised that at the beginning of their design experience they are not fully aware of the different problem types that they have to tackle and the questions that they should ask. The design process requires designers to solve problems to decompose, embody and assign functions as well as to diagnose malfunctions. This means that the questions asked when designing most probably vary depending on the problem types being addressed. Empirical research has shown that novice designers approach experienced colleagues not only to acquire the information to progress their design tasks but

also to understand what questions to ask [3]. This suggests that experience leads designers to asking more pertinent questions and that supporting novice designers with the right questions to ask could be a means of providing them with guidance through design processes.

In addition, if empirical research has shown that the questions asked when designing have a direct bearing on design performance [2], it can be expected that the types of question asked by designers have also a direct influence on the quality and speed of design processes.

### 2.2 Current research to understand design reasoning questions

Initial interest in researching the questions asked when designing was driven by the intention to understand how to manage knowledge and information in the design process and consequently inform the development of tools and methods to support designers [4, 5]. Subsequent research into design questions focused instead on understanding design activities [6, 7]. In the design process, questions are asked to access the information to progress design tasks, to reason and deliberate about products and processes as well as to develop strategies. The classifications of questions proposed by the above authors are now reviewed.

Gruber and Russell, guided by the question-forming vocabulary, identified 14 classes of questions [4]. Baya, investigating the information handling behaviour of designers and building upon Kuffner and Ullman research work [8], identified 11 classes of questions. The research showed that designers do not form questions randomly; do not carry out design with a predefined set of questions; and form new questions after reflecting on information received in answer to previous questions [5].

Ahmed, investigating the different strategies adopted in the design process by novice and experienced designers, identified 8 classes of strategic questions [6].

Eris, exploring the nature of questions asked when designing and expanding existing knowledge of questions by Lehnert and Graesser [9, 10], proposed 22 classes of question [7]. The higher-level classes of question were divided into two groups termed Deep Reasoning Questions (DRQs) and Generative Design Questions (GDQs). If the DRQs aim at understanding facts, the GDQs aim at creating possibilities from facts. The research found that question-asking is used by designers as a mechanism to manage convergent and divergent thinking.

The classification of questions proposed by Eris is the only one that indicates a structure, i.e. the remaining classifications are flat. In general, the classifications found in the literature fail to indicate the relation between the classes of question identified and the activities and problems undertaken when designing. This finding led to the analysis of these classifications in order to identify important characteristics of questions that could be used in the development of a new characterisation.

## 3 UNDERSTANDING REASONING QUESTIONS

### 3.1 Methods

After reviewing existing classifications of questions, empirical research was undertaken to understand the questions asked by designers in industry.

The empirical research consisted of undertaking three studies: ethnographic participation, diary study and observations with shadowing. During the participation the researcher carried out design work for nine weeks within an engineering design department. The follow-up studies were all undertaken within the same department. The diary study was conducted for five-week. Twelve designers agreed to self-record their questions whenever they occurred. In order to strengthen the investigative capability of this method, in-depth semi-structured interviews with audio recording were undertaken at the end of each week. The observations with shadowing were undertaken with ten designers for seven hours each. Prior to the start of an observation, each participant was asked to follow his or her daily schedule and to think aloud to describe any question. Two large data sets of design questions were collected. The data sets include product reasoning questions as well as other types of design questions. The analysis of the data sets allowed the development of the characterisation of questions presented in this paper.

At a later stage, further empirical research consisted of testing the characterisation through a new data set of questions. This data set was extracted from the argumentation maps that seven designers generated while undertaking their design processes using a software tool called DRed. The tool aims at supporting designers by allowing them to structure their design processes through the use of three key element types: issue, answer and argument. The design tasks undertaken by the designers studied in this research are variant designs, i.e. the work usually involves incremental innovation to extend existing product solutions.

### 3.2 The characteristics of product reasoning questions

The analysis of existing question classifications and that of the data collected in this research allowed the identification of important characteristics of design questions as follows:

- *objective*: intent of the question;
- *subject*: major object of interest of the question;
- *response process*: cognitive process involved in answering the question;
- *response type*: answer to the question; and
- *problem type*: problem progressed by answering the question.

These characteristics were identified analysing the forming vocabulary of questions and their context. Product reasoning questions, a particular subset of design questions, are closely related to problem solving. These questions are asked and answered to progress specific processes. The *objective* of a product reasoning question is that of the process that a designer intends to progress and its *response process* is reasoning. A product reasoning question is asked to address a specific *problem type*. The *subject* of a product reasoning questions is always the product to be developed and the *response type* varies depending on the stage of definition of a design.

Product reasoning questions are formed to pursue different *objectives* that form a problem solving pattern. These objectives include *generation*, *analysis* and *evaluation*. Consider for example the following three product reasoning questions to embody a function:

- *How can we adequately lubricate and cool the front roller bearing (FRB) at a low cost?*
  This question has the objective to *generate* a design solution, i.e. a satisfactory concept for lubrication and cooling.
- *What oil quantity and angle cone does a side jet nozzle allow us to obtain?*
  This question has the objective to *analyse* a design solution, i.e. the side jet nozzle.
- *Do these values for the oil quantity and the oil jet angle cone meet out lubrication and cooling requirements?*
  This question has the objective to *evaluate* the design solution.

Product reasoning questions are answered through transformations and comparisons. In particular, the questions to generate and analyse a solution are answered by transformation, whereas those to evaluate a solution by comparison.
A transformation consists of moving from an initial proposition (IP) to a final proposition (FP). The forming vocabulary of a product reasoning question to pursue generation or analysis generally describes the IP of the transformation to be undertaken and expresses the intent to move towards a FP. Consider again the question: *How can we adequately lubricate and cool the front roller bearing at a low cost?* This question aims at undertaking a transformation from the IP (*provide oil to lubricate and cool the front roller bearing*) to the FP (*satisfactory concept for lubrication and cooling*) in order to *generate* a design solution.
A comparison consists of identifying similarities or differences between the initial proposition (IP) and the final proposition (FP). Consider for example the following question: *Do these values for the oil quantity and oil jet angle cone meet our lubrication and cooling requirements?* This question aims at undertaking a comparison between the IP (*newly estimated values for oil quantity and oil jet angle cone*) and the FP (*lubrication and cooling requirements*) in order to *evaluate* a design solution.

Product reasoning questions are formed to tackle different *problem types*. These problems include functional decomposition, function embodiment, function assignment and malfunction diagnosis. Functional decomposition and function embodiment are directly undertaken to develop new designs. Function assignment is undertaken to match a certain component or assembly with a particular function. Malfunction diagnosis is undertaken to identify which component or assembly does not work as it is intended to.

Overall, product reasoning questions appear to indicate different objectives that can be identified analysing their forming vocabulary and consequently used to distinguish them. These objectives form a problem solving pattern including generation, analysis and evaluation. Some objectives are associated to transformations and others to comparisons. In addition, it was shown that the forming vocabulary of a product reasoning question allows identifying the IP and FP of the associated process. An example of addressing a function embodiment problem was presented. However, product reasoning questions were found to be formed also to tackle other problems. An important research issue therefore emerged associated to this last characteristic of product reasoning questions: how can product reasoning questions be distinguished depending on the problem type? In order to address this issue, the focus was placed on the IP and FP the processes that product reasoning questions attempt to progress. Starting from the consideration that the subject of product reasoning questions is always the product being designed, the possibility was investigated of characterising the IP and FP of these questions through descriptions of a product in terms of behaviour, form and other issues driving the design process. This approach appeared promising so research was undertaken to model the problems tackled by designers and to see if product reasoning questions allow the description of these models.

### 3.3 Modelling the problem types tackled by designers

Engineering designers form product reasoning questions to tackle four main problem types, i.e. functional decomposition, function embodiment, function assignment and malfunction diagnosis. These problem types have a common underlying problem-solving model consisting of generating hypotheses and testing them through analysis and evaluation, see Figure 1.

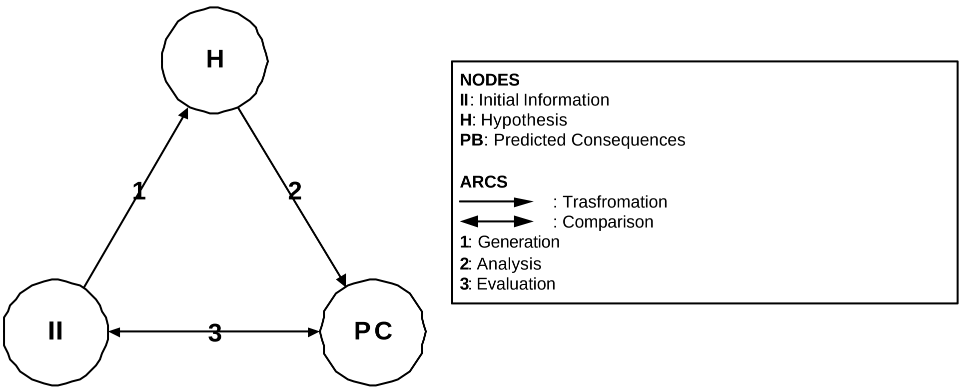


*Figure 1. Generic problem solving model*

The model consists of a graph where arcs link nodes. The nodes describe different states of the developing hypothesis. The arcs describe three processes, i.e. two transformations and a comparison each of which has a specific objective. The starting point of the model is the initial information. The first transformation has the objective to *generate* one or more hypotheses (FP) from the initial information (IP). The second transformation has the objective to *analyse* the hypotheses (IP) in order to predict their consequences (FP). Finally, the comparison has the objective to *evaluate* the predicted consequences (IP) against the initial information (FP). It is noteworthy that the initial information, the hypotheses and the predicted consequences differ depending on the problem type being addressed. Figure 2 shows how the generic problem solving model can be adapted to the four problem types previously presented.

The nodes describe different states of the developing product through three classes of variables:

- Form variables: describe the components of an artifact and their relationships;
- Behaviour variables: describe the whole complex of transformations that occur to an artifact and its context during its use;
- X variables: describe any additional issue driving the design process.

The arcs describe a set of processes linking form, behaviour and X.

The three processes for each problem type are briefly outlined below:

- *functional decomposition*: (1) generation transforms an intended function (IB') into a function structure (IB(X)); (2) analysis derives a predicted behaviour (PB) from a function structure

(IB(X)); and (3) evaluation compares the predicted behaviour (PB) against the initial intended function (IB’), see Figure 2. This model is in line with the findings by Bracewell and Sharpe [11].

- *function embodiment*: (1) generation transforms a function (IB(X)) into a form (F); (2) analysis derives a predicted behaviour (PB(X)) from a form (F); and (3) evaluation compares the predicted behaviour (PB(X)) against the initial function (IB(X)), see Figure 2. This model is in line with the findings by March, Gero, and Gruber and Russell [12, 13, 14].
- *function assignment*: (1) generation transforms a form (F) into a function (IB); (2) analysis derives a predicted behaviour (PB) from a form (F); and (3) evaluation compares the predicted behaviour (PB) against the hypothesised function (IB), see Figure 2. This model is supported by an empirical study of the differences in reading schematic drawings of mechanisms by expert and naive mechanical designers conducted by Waldron [15] and is in line with the findings from Kroes [16].
- *malfunction diagnosis*: (1) generation transforms an unsatisfactory observed behaviour (OB) into a cause (F); (2) analysis derives a predicted behaviour (PB) from a cause (F); and (3) evaluation compares the predicted behaviour (PB) against the initial problem (OB), see Figure 2. This model is in line with the findings by Patel and Ramoni in the medical field [17].

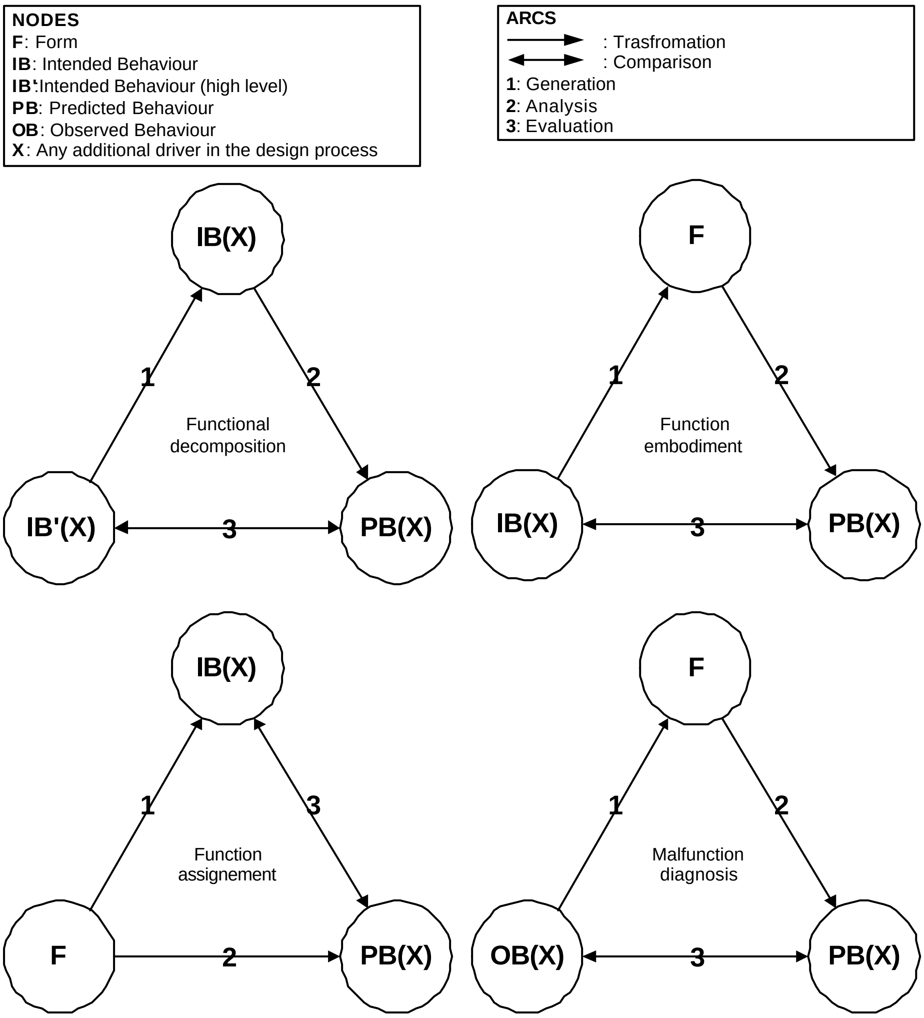


*Figure 2. Modeling four problem types*

Four models were developed each of which is associated to a problem type and consists of pursuing the same three objectives, i.e. generation, analysis and evaluation. In most cases the objective of a process together with its IP and FP allow to distinguish uniquely a process. Consider for example how generation in *function embodiment* consists of moving from IB(X) to F and generation in *function assignment* consists of moving from F to IB(X). Consider instead how analysis consists of moving from F to PB(X) both for *function embodiment* and *malfunction diagnosis*.

Once the problems were modelled, research was undertaken to understand if the examples of product reasoning question in our data sets allowed us to describe the processes outlined in the four models.

### 3.4 Characterising product reasoning questions

The analysis of the literature and that of the data sets used in this research led to the development of two categories termed *objective* and *reasoning direction*. Each category includes a number of data-driven types.

The *objective* category includes three types that characterise different intents indicated by product reasoning questions, see Table 1. These types describe the following pattern: generation, analysis and evaluation of solutions.

*Table 1. Objective category*

| Objective | Description |
|---|---|
| O1: Generation | The question wants to generate a solution. *Ex.: How can I retain the seal in place?* |
| O2: Analysis | The question wants to establish the consequences of a solution by carrying out simulation and calculation. *Ex.: What is the impact on stress of increasing the OD of the shroud?* |
| O3: Evaluation | The question wants to establish: (i) if a solution is satisfactory or not; and (ii) the degree of merit of a number of solutions by relative comparison. Ex.: *Is the stress in the HPIP hub acceptable?* |

The *reasoning direction* category includes eight types that characterise different directions indicated by product reasoning questions, see Table 2. It is noteworthy that each direction is presented together with its associated objective and problem type. These directions have been identified based on the initial proposition (IP) and final proposition (FP) of the processes that the questions in our data sets intended to progress. The IP and FP of each direction were characterised through descriptions of a product in terms of behaviour, form and other drivers in the design process (X).

*Table 2. Reasoning direction category*

| Reasoning direction | Objective | Problem type |
|---|---|---|
| D1: IB (X) to IB (X) | Generation *(transf.)* | Functional decomposition |
| D2: IB (X) to F | Generation *(transf.)* | Function embodiment* |
| D3: F to IB | Generation *(transf.)* | Function assignment |
| D4: OB (X) to F | Generation *(transf.)* | Malfunction diagnosis |
| D5: IB (X) to PB(X) | Analysis *(transf.)* | Functional decomposition |
| D6: F to PB (X) | Analysis *(transf.)* | Function embodiment*, function assignment and malfunction diagnosis |
| D7: PB (X) to IB (X) | Evaluation *(comp.)* | Functional decomposition, function embodiment* and function assignment |
| D8: PB (X) to OB (X) | Evaluation *(comp.)* | Malfunction diagnosis |
| F: form; IB: intended behaviour; IB': intended behaviour (high level); PB: predicted behaviour; OB: observed behaviour; X: any additional driver in the design process | | |

Direction D6 and direction D7 are common to three problem types, see Table 2. This means that three out of the four problems modelled in Figure 2 have the same type of process in analysis as well as in evaluation. In Table 2 some problem types have been shaded to indicate that questions describing the corresponding direction were not identified. Consider for example direction D7 and note that questions describing this direction were identified only for the *function embodiment* problem.

Overall, this means that the actual directions identified were 7. It is interesting that the analysis of our data sets of questions led to the identification of 7 out of the 12 directions. A possible explanation for this result can be found in the type of design activity during which the questions were collected and the size of the data sets analysed. Not surprisingly, the function embodiment model is the only one for which questions characteristic of the three objectives were identified, see asterisk in Table 2.

Product reasoning questions were found to have objectives like those typical of the generic problem solving model presented in Figure 1. In addition, these questions were found to describe the directions characteristic of the four problem solving models. However, it is important to state that the questions in our data sets allowed us to match only 60% of the directions. Although it is expected that designers ask also questions characteristic of the remaining directions, these have not been identified yet.

The next sections present examples of product reasoning questions describing each of the four problem models. The questions are presented together with their answers in order to show how a solution to each problem is generated and tested. It is important to state that some of the example questions were made up by the author. The design problems used in this paper were either extracted from the data collected during this research or borrowed from other researchers.

#### *3.4.1 Functional decomposition*

The example of the design of a hydraulic arm, originally presented by Porter [18], is now considered. The function to be realised is moving objects from one position to another as rapidly as possible while keeping accelerations below a certain threshold. In order to decompose this function, a designer would require to ask the following three questions and find corresponding answers, see Figure 3.

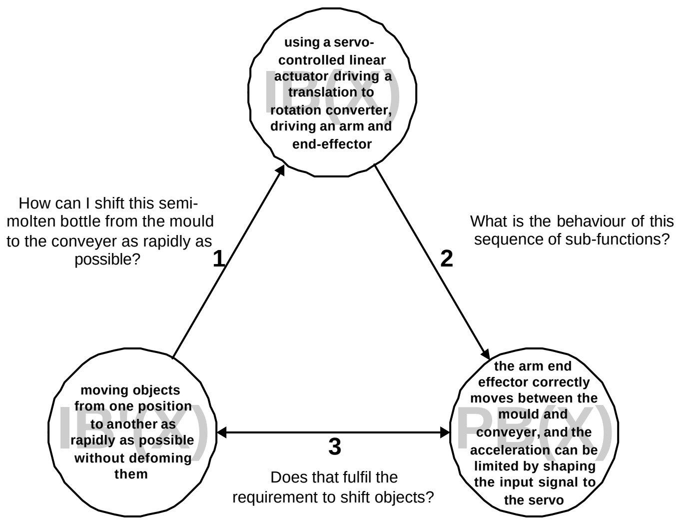


*Figure 3. Functional decomposition*

#### *3.4.2 Function embodiment*

The example of the design of the oil jet nozzle for a gas turbine fan front roller bearing (FRB) is now considered. The function to be realised is providing the FRB with oil for lubrication and cooling purposes at a low cost. Previously the FRB has been under race fed. Under race feed is effective at distributing the oil to the bearing but it is also expensive to produce. In order to embody this function, a designer would require to ask the following three questions and find corresponding answers, see Figure 4a.

The example of the design of a dishwasher for a sailing boat, originally proposed by Roozenburg and Eekels [19], is now considered. A dishwasher for a sailing boat must function properly under rough swell and large angles of lean. The function to be realised is unbroken, dirty dishes must become unbroken, clean dishes, within one hour and with the help of seawater. A designer asking himself what properties the dishwasher needs, may assume that the dirty dishes should follow the ship's movements as little as possible, and formulate the following requirement: the dishes must stay in a horizontal position. In order to embody this function, such designer would require to ask the following three questions and find corresponding answers, see Figure 4b.

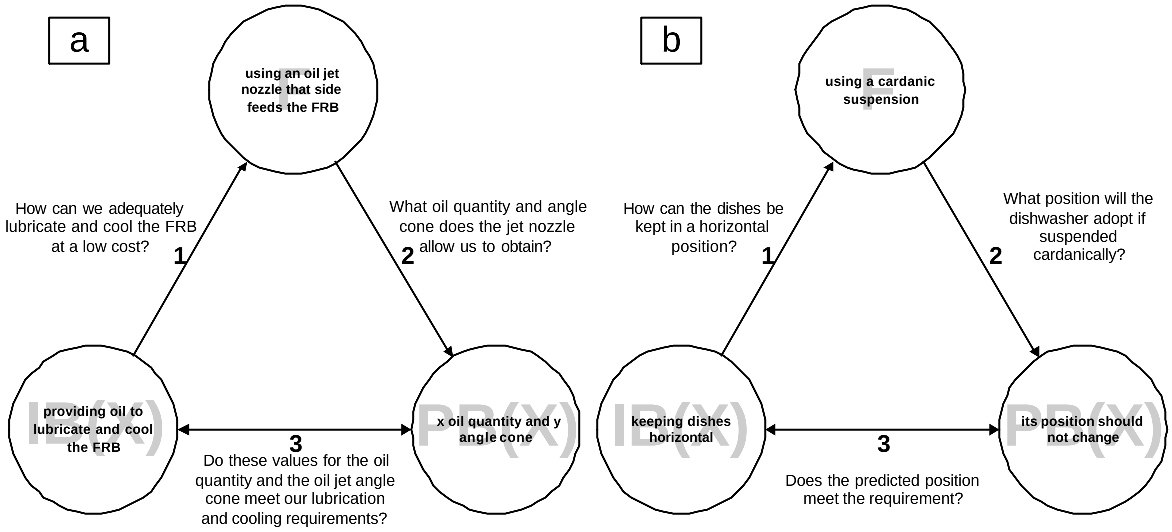


*Figure 4. Function embodiment*

#### *3.4.3 Function assignment*

The design of a hair dryer consisting primarily of an electrical heating element and a DC-motor driving a fan, originally presented by Jensen [20], is now considered. The heating element is made of a thin wire wound in a spiral. The motor requires a power supply of 24VDC. Therefore a 230V-24V transformer and a rectifier must be introduced to the design. The AC-voltage transformation may be based on several principles, e.g. electromagnetic as in toroidal transformers or electronic as in switch mode transformers. However each of these kinds of transformers introduces a new structural element to the design. Unsatisfied by these solutions, a designer, working on this problem and focusing on the heating element, could ask the following three questions and find corresponding answers, see Figure 5.

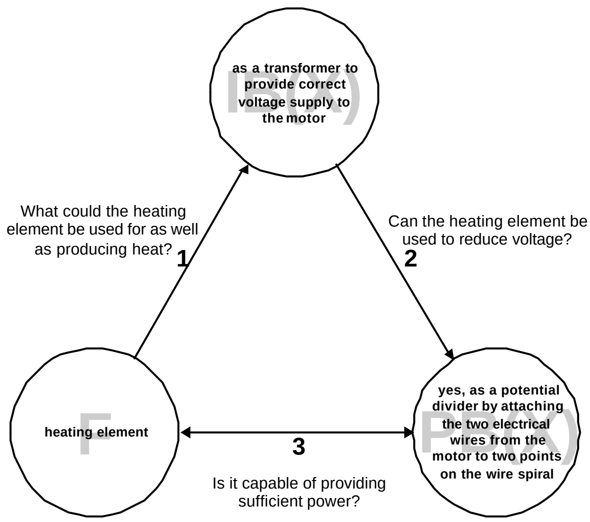


*Figure 5. Function assignment*

#### *3.4.4 Malfunction diagnosis*

The example of the design of the oil jet nozzle for a gas turbine fan front roller bearing (FRB) is now considered again. Assume that during strip of the development engine it became evident that oil had been leaking from the front bearing housing (FBH) hub in to the buffer region. In order to identify the reason for this malfunction, a designer would require to ask the following three questions and find corresponding answers, see Figure 6a.

The example of the design of a dishwasher for a sailing boat is now considered again. Assume that further development in the design activity have led to an embodied concept for a cardanic suspension and a physical prototype, and a testing phase is to be undertaken. The prototype is tested at wind force 9 on the Ijsselmeer and things go wrong: all shot glasses are broken, and the dirty dishes are not clean. A reason for the malfunction has to be identified. In order to do that, a designer would require to ask the following three questions and find corresponding answers, see Figure 6b.

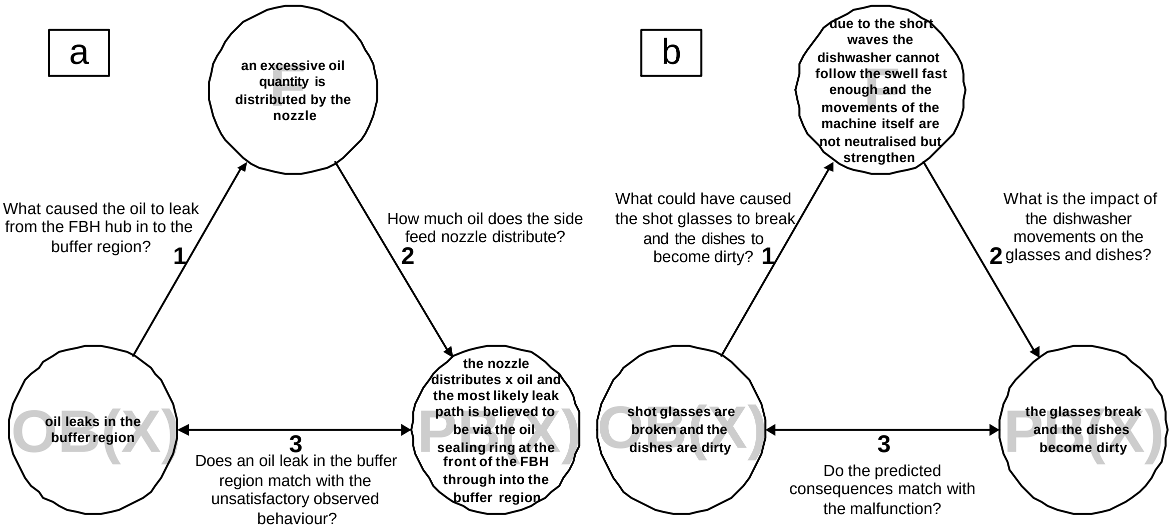


*Figure 6. Malfunction diagnosis*

### 3.5 Discussion

The *objective* category introduced the idea of intent of a question. Product reasoning questions were found to have the same objectives required to problem solve, i.e. generation, analysis and evaluation. However, it is important to say that design questions have also other objectives. In particular, some questions do not have an objective (their only intent is to obtain information) and others indicate objectives like confirmation and comparison. These questions are generally used by designers to acquire factual information.

The *reasoning direction* category allowed us to characterise the processes that product reasoning questions intent to progress and simultaneously to differentiate them by problem type. Although this approach to classifying product reasoning questions was very useful for identifying many subtle differences in the data, it showed some limitations. In particular, it did not allow distinguishing questions to carry out analysis depending on the problem type, see Table 2. Note for example that direction D6 in Table 2 is common to function embodiment, function assignment and malfunction diagnosis.

The identification of questions that describe the *function embodiment* model provided an empirical evaluation of its validity and showed that question asking represents a valuable approach to solving design problems. The remaining three models were only partially described using product reasoning questions. Further research has to be undertaken to better understand the processes behind these models and prove their validity.

## 4 CONCLUSIONS

Engineering designers progress their tasks by asking questions and finding satisfactory answers. Design questions are raised to design new products as well as to develop processes and strategies. A review of existing question classifications identified the need to develop more understanding of design questions and to establish their relation to the activities of problem solving and the problems tackled in the design process. Empirical research was carried out using an ethnographic participation, a diary study and observations with shadowing. The methods employed in this research led to the collection of rich data sets of questions. The research focused on studying a subset of design questions termed product reasoning questions. The categories and the types developed during data analysis allowed the identification of new differences in these questions. In particular, the research showed that product reasoning questions have the same objectives required to problem solve and describe processes to solve different problem types. The categories resulting from this research were then successfully tested using questions extracted from the argumentation maps generated by seven designers.

## ACKNOWLEDGEMENTS

The authors acknowledge the support of EPSRC and Rolls-Royce through the UTP for Design.

## REFERENCES

[1] Bucciarelli, L.L. An ethnographic perspective on engineering design, *Design Studies*, 9, 159-168, 1998.
[2] Eris, O. Asking Generative Design Questions: A Fundamental Cognitive Mechanism in Design Thinking, in *Proceedings of the International Conference on Engineering Design*, Stockholm, Sweden, 2003.
[3] Ahmed, S. and Wallace, K.M. Understanding the knowledge needs of novice designers in the aerospace industry', *Design Studies*, 25(2), 155-173, 2003.
[4] Gruber, T.R. and Russel, D.M. Derivation and Use of Design Rationale Information as Expressed by Designers, Technical Report, 1992.
[5] Baya, V. Information Handling Behaviour of Designers during Conceptual Design: Three Experiments, PhD Thesis, Department of Mechanical Engineering, Stanford University, 1996.
[6] Ahmed, S, Wallace, KM and Blessing, LTM, Understanding the differences between how novice and experienced designers approach design tasks, *Research in Engineering Design*, 14(1), 1-11, 2003.
[7] Eris, O. Perceiving, comprehending, and measuring design activity through the questions asked while designing, PhD Thesis, Department of Mechanical Engineering, Stanford University, 2002.
[8] Kuffner, T.A. and Ullman, D.G. The Information Request of Mechanical Design Engineers, Design Studies, 12(1), 1991.
[9] Lehnert, G.W. The Process of Question Answering, Lawrence Erlbaum Associates, Hillsdale New Jersey, 1978.
[10] Graesser, A and McMahen, C. Anomalous Information Triggers Questions When Adults Solve Quantitative Problems and Comprehend Stories, *Journal of Educational Psychology*, 85(1), 136-151, 1993.
[11] Bracewell, R.H. and Sharpe, J.E.E. Functional descriptions used in computer support for qualitative scheme generation - "Schemebuilder", *AI EDAM Journal*, 10 (Special Issue: Representing Functionality in Design, 4), 333-346, 1996.
[12] March, L. The Logic of Design, in N Cross (ed.) Developments in Design Methodology, John Wiley & Sons, Chichester, pp. 265-276, 1984.
[13] Gero, J.S. Design prototypes: a knowledge representation schema for design, *AI Magazine*, 11(4), 26-36, 1990.
[14] Gruber, T.R. Generative Design Rationale: Beyond the Record and Reply Paradigm, 1993.
[15] Waldron, MB, Waldron, KJ and Abdelhamied, K. The differences in reading schematic drawings of mechanisms by expert and naive mechanical designers, in *ICED*, pp. pp.15-21, 1987.
[16] Kroes, P.A. Technological Explanations: The Relation Between Structure and Function of Technological Objects, *Journal of Society for Philosophy and Technology*, 3(3), 1998.
[17] Patel, V.L. and Ramoni, M.F. Cognitive Models of Directional Inference in Expert Mediacal Reasoning, Expertise in Context - Human and Machine, The MIT Press, Menlo Park, California, pp. 67-99, 1997.
[18] Porter, I. Schemebuilder mechatronics, in Proceedings of the engineering design conference '98: design reuse, Brunel University, pp. 561-8, 1998.
[19] Roozenburg, N.F.M. and Eekels, J. Product Design: Fundamentals and Methods, John Wiley & Sons, Chichester, 1995.
[20] Jensen, T. Function Integration Explained by Allocation and Activation of Wirk Elements, in *ASME Design Theory and Methodology*, Baltimore, Maryland, USA, 2000.

Contact: Aurisicchio Marco
University of Cambridge
Department of Engineering
Trumpington Street
CB2 1PZ, Cambridge
United Kingdom
Phone: 0044 01223 760571
Fax: 0044 01223 760567
e-mail: ma248@eng.cam.ac.uk