INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 05 MELBOURNE, AUGUST 15-18, 2005

THE ROLE OF KNOWLEDGE AND EXPERIENCE IN ENGINEERING DESIGN

Saeema Ahmed, Paul Hacker and Ken Wallace

Abstract

This research aims to understand the importance of different types of knowledge to engineering and to understand the number of years of relevant experience required to become an expert in these types of knowledge. The findings of this research contribute to the education and the training of engineering designers, and to validating classifications of knowledge proposed in literature. This paper describes the findings from an empirical study carried out with engineers in managerial roles. Their views have been collected and analysed and are presented in this paper.

Keywords: Empirical studies, design knowledge, future vision, experience

1 Introduction

Knowledge and experience play an important role in engineering design and managing knowledge is an important concern for industry, including engineering. Engineering firms are facing pressures to increase the quality of their products, to have even shorter lead times and reduced costs. Other motivations for managing knowledge are to provide a trail for product liability legislation and to retain knowledge and experience as engineering designers retire. Trends in career patterns have changed, typically an engineer would view a job in a large aerospace company as a job for life. Expertise, which is built up through exposure to problem solving situations, takes time to acquire. It is argued that it takes at least ten years of exposure before one can be considered an expert in a particular field [1].

Knowledge provides the capacity to make decisions and adopt courses of action. Knowledge is generated and evolves: (1) by observing and experiencing; (2) by interpreting information and data; and (3) through reasoning and combining pieces of knowledge. Many classifications of the knowledge employed in engineering design have been proposed [2,3]. Some of these are discussed in this paper and later used to understand the findings of the empirical study described.

A common way of classifying knowledge is whether knowledge can be articulated or not, i.e. explicit and tacit knowledge [4,5] and some researchers include implicit knowledge [6]. Explicit knowledge can be articulated. Once articulated, it can be represented as information, e.g. written down, and thus stored externally and transferred as information. The laws of physics used for calculations are an example of explicit knowledge. Tacit knowledge cannot be articulated, but its role in the design process can be investigated. An example of tacit knowledge is the intuitive feel that an experienced designer has for the correct shape of a component in a product. A third category is implicit knowledge, which is not easily articulated by the person possessing it, but can be elicited and articulated by others. An example of implicit knowledge is the strategy adopted by an experienced designer to undertake a particular task in the design process. This category is useful when understanding management of knowledge. Domain knowledge in the field of engineering design is gained through study and experience within a specific domain the designer works in [7]. Evbuoimwan states that two types of design knowledge exist: that associated with the product; and that associated with the process [8]. Product knowledge is concerned with the artefact to be designed, whereas process knowledge is concerned with the activity of designing itself [3]. An example of product knowledge is the knowledge concerned with calculating the number of blades for an Intermediate-Pressure turbine. An example of process knowledge is knowledge of specific design methodologies such as systematic evaluation. Table 1 describes explicit, implicit and tacit knowledge with examples of both product and process knowledge.

	EXPLICIT KNOWLEDGE	IMPLICIT KNOWLEDGE	TACIT KNOWLEDGE
PROCESS	Explanations about the process (e.g. Rationale)	Understanding about the process (e.g. Strategies)	Intuition about the process (e.g. Insights)
PRODUCT	Explanations about the product (e.g. Rationale)	Understanding about the product (e.g. Relationships)	Intuition about the product (e.g. Insights)

Table 1 Process and Product Knowledge classifications

Venselaar distinguishes knowledge into domain specific and general knowledge, each of these types of knowledge is classified further into four different types [9]. These are summarised in Table 2 and are described below, the definitions have been adapted for clarity.

1. declarative knowledge, which is commonly described as factual knowledge. Declarative knowledge contains the facts and principles in a particular domain An example of declarative knowledge for an Intermediate-Pressure turbine blade would include knowledge of its features (shroud, shank, platform, aerofoil, etc.).
2. procedural knowledge, is about *how* to undertake some action, whereas declarative (or factual) knowledge is *about* some thing [10]. Procedural knowledge associated with an Intermediate-Pressure turbine blade would include knowledge about the process by which one is designed.
3. situational knowledge is the knowledge of understanding the context in which knowledge is applied, i.e. where, how and when.
4. strategic knowledge is described as knowledge of processes that are systematic and consciously invoked to facilitate the acquisition an utilization of knowledge. Research undertaken to understand differences between novices and experienced designers found that strategic knowledge is not necessarily consciously invoked and maybe implicit knowledge [11]. Strategic knowledge is often attributed to experienced engineering designers rather than less experienced engineering designers [12, 13, 14].

	Domain-specific knowledge Basic knowledge	 Domain knowledge	General Process
Declarative knowledge	Knowledge of facts and formulas	Knowledge of design facts and methods	Knowledge of methods to optimise the process
Procedural knowledge	How to use these facts and formulas	How to use these design facts/methods	How to use these design facts/methods
Situational knowledge	When and where to use this basic knowledge	When and where to use this design knowledge	When and where to use the this process knowledge
Strategic knowledge	Knowledge of algorithms and heuristics of relevant domains	Knowledge of heuristics in solving design problems	Knowledge of algorithms and heuristics in problem solving

Table 2 Classifications of knowledge [9]

One of the difficulties with these knowledge classifications is distinguishing between the difference types of knowledge, for example the distinction between process and strategic knowledge [2]. A second problem is that there are rarely validated and hence finding examples of these knowledge in design can be difficult. The approach undertaken for this research was to allow the engineering designers to describe the types of knowledge undertaken and then compare these to existing classifications.

2 Research approach

A total of 26 interviews were carried out with the senior level engineering designers. All of the participants had extensive experience within the aerospace industry and were either chief engineers or heads of their business units with significant responsibility for a number of engineering designers. The participants represented all of the major sites of the company including UK, USA, Canada and Germany. These interviews were carried out by telephone due to a number of reasons. Firstly, since the participants were at a senior level within the company and therefore very busy, the interviews were constantly rearranged, by conducting the interviews by telephone valuable time was saved. Secondly, the participants were located in four countries and two continents, hence, for practical reasons to ensure consistency between interviews, all interviews were conducted by telephone rather than conducting a mixture of face-to-face interviews and telephone interviews. Prior to the interviews the designers were provided with an electronic document, which was referred to during the interview. The designers were provided with the questions that would be asked during the interviews, to ensure that they had the time to prepare. However, it was not assumed that all the participants would have the time to prepare and hence, sufficient time was allocated for the interviews. The interviews were scheduled for an hour and lasted less than this period. The interviews were structured, although opportunity was provided for the participants to provide any views at the end of the interview.

As the interviews were undertaken over a period of a few months (due to the schedules of the participants), care was taken to ensure that none of the expected results were communicated to avoid any biasing of the results.

2.1 Method of analysis

A total of 24 types of knowledge required by engineering designers working in the aerospace industry were identified prior to the interviews. The coding scheme consisted of these twenty-four categories describing process knowledge; product knowledge and management knowledge. The coding scheme was developed in an iterative process during an independent research project where 860 engineers participated in a survey to assess their knowledge [15]. In addition to these 24 knowledge categories, eight personal attributes were also identified. These personal attributes were: creator and innovator, finisher, challenger, decision-maker, organiser, communicator, team worker and, leader. However these were not investigated for this particular research due to the subjective nature of assessing these attributes.

The 26 participants were provided with definitions for each of the knowledge categories in advance of the interviews. The participants were asked to check these coding scheme for completeness both prior to the interviews and again during the interviews. The terminology used within the company was used to describe the categories of the coding scheme was those. The coding scheme is described in this paper using terminology from literature.

Ten categories described knowledge of the product, e.g. the entire product, in this case aero-engine, and of each of the different assemblies. One category described the knowledge of the whole product, i.e. the aero-engine and the remaining nine described the various modules that form the part of the aero-engine. This part of the categorising scheme is specific to the product being designed, however the findings from here are applicable to other complex products involving a large number of designers and components.

Twelve categories were used to describe the process knowledge and two categories describe knowledge required for managerial knowledge (see Table 3). The categories describing managerial knowledge are from the perspective of engineering designers managing their design projects whilst designing, as opposed to engineering designers who are working in managerial roles. Table 3 summarise all of the process and managerial knowledge, the relevant knowledge classification from literature is presented in the third column.

Type of knowledge	Definition	Knowledge classification
Conceptual design	The designer is dealing with the whole product or whole assemblies and works from a blank sheet of paper, generating and evaluating several ideas.	Procedural knowledge Strategic knowledge
Detailed design	The knowledge required to define specific components including technical drawings and specifying manufacturing requirements.	Procedural knowledge Strategic knowledge
Analyse and verify	The knowledge required to analyse and verify a design, this may be conducted by the designer. Sufficient knowledge is required to be able to set up any necessary tests and to be able to challenge results from a formal analysis.	Procedural knowledge Strategic knowledge
Compliance with standards	Knowledge to ensure design complies with standards and legislation.	Procedural knowledge Declarative knowledge
Design for X	Knowledge to improve a design from a particular perspective, e.g. cost or quality- not necessarily employing a formal design for x method or tool.	Procedural knowledge Strategic knowledge
Knowledge of assembly	Knowledge of how the product will be assembled and of assembly plans.	Procedural knowledge
Design for service	Considering the product through its service i.e. once released, for example inspection or monitoring components for wear limits, etc.	Procedural knowledge
Managing requirements	Managing requirements and assessing the risk of these requirements not being achieved for each component.	Procedural knowledge
Physical integration	Ensuring that interfacing components physically fit together.	Procedural knowledge
Functional integration	Knowledge required to integrate the function of a component with other component or assemblies that share the function.	Procedural knowledge
Investigating and identifying the problem	Investigative and diagnostic work to identify the problem and may be applied to major quality failures.	Procedural knowledge
Engineering processes and methods and tools	Knowledge of the impact of engineering processes, methods and tools	Procedural knowledge Strategic knowledge
Managing time and cost requirements	Designers ability to deliver design to schedule and cost	Procedural knowledge
Managing resources	Knowledge of line management, e.g. setting objectives, training, etc.	Procedural knowledge

Table 3 Categorisation of knowledge

Prior to the interviews, the participants were supplied with all necessary material including definitions of each of the categories and a list of questions. The designers were asked:

- to rate the importance for 24 knowledge categories
- to estimate the number of years required to be an experienced designer and an expert in that particular type of 24 categories. The participants view on what the differences between an expert and an experienced designer was also recorded.
- to identify any other types of knowledge recognised as important that had been omitted from the coding scheme.

3 Findings

The interviews were analysed to identify the types of knowledge that are perceived as important to an engineering designer today. The designers were asked to rate the importance of each type of knowledge from a scale. The scale consisted of four categories: not important; slightly important; important and; very important. It was found that process knowledge was perceived as more important for an engineer than product knowledge or managerial knowledge (refer to Figure 1). The process knowledge categories were perceived as between important to very important (this is discussed in more detail later in this section), whilst knowledge related to the product was rated lower on average (between slightly important and important). The categories describing managerial knowledge were also related as between slightly important and important. Knowledge about the process is thought to contribute to creativity, Christiaans found that first year design students whose projects were judged as creative also had a higher level of general process knowledge [2].

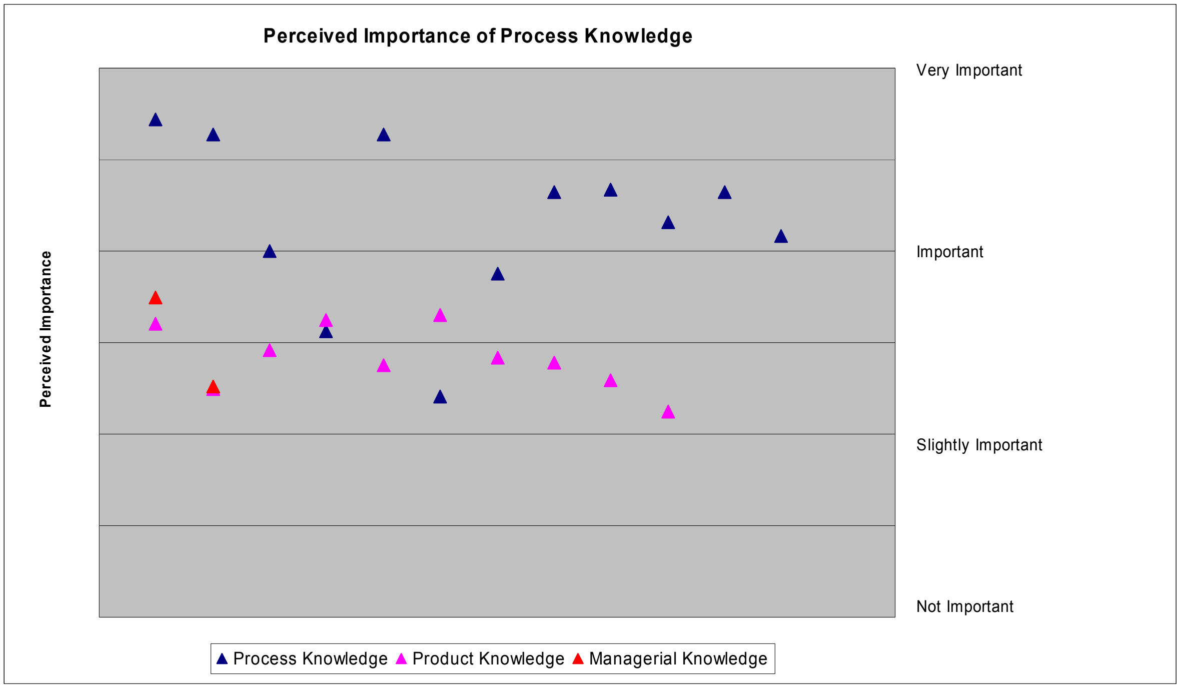

Figure 1 Perceived importance of types of knowledge

Knowledge related to the process was perceived as the most important type, with most of the twelve categories being described as between important and slightly important. There were three exceptions to this: knowledge of assembly, compliance with standards and design for service were perceived as between slightly important and important (refer to Figure 2). All of these three types of knowledge are related to considering a particular issue, i.e. considering standards, or considering life-cycle issues such as assembly and 'the use' or service stage of the product. Three types of knowledge were perceived as the most important and these were knowledge of how to undertake: (1) conceptual design; (2) detailed design; and (3) design for X, i.e. designing to improve quality and/or lower cost. On average, all of these were perceived as between important and very important.

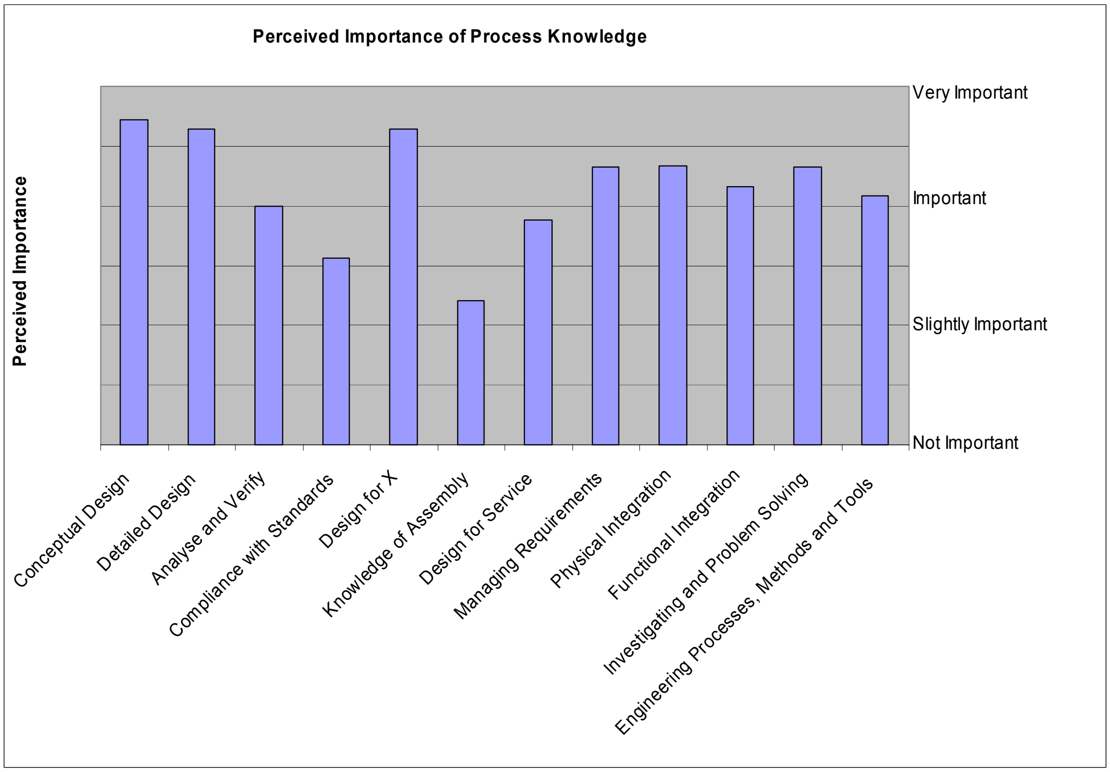

Figure 2 Perceived importance of process knowledge

The interviews were analysed to identify the number of years to become an expert in each of the knowledge categories. The participants were asked how many years of relevant experience is required to become an expert and to become an experienced engineering designer for each of the knowledge categories that they had perceived to be important. The participants were all responsible for a number of experts and experienced engineering designers for their particular business unit. The difference between the answers provided for the number of years to become an expert in anyone knowledge type was an additional two to three years on average to that to become an experienced designer in that knowledge type (refer to Figure 3 for those related to process knowledge). However, it was recognised that an expert is not simply a very experienced designer, but other factors contribute. The factors that were mentioned in the interviews were related to personal attributes such as creativity. It was also stated that in order to become an expert exposure to a range of experience and problems was required. Experience is thought to increase creativity by providing more opportunities to generate a design solution and, thus increase the chance of finding a better solution [16]. The ability of experienced designers to organise information in their mind is thought to support the recognition of a creative and unusual solution [17].

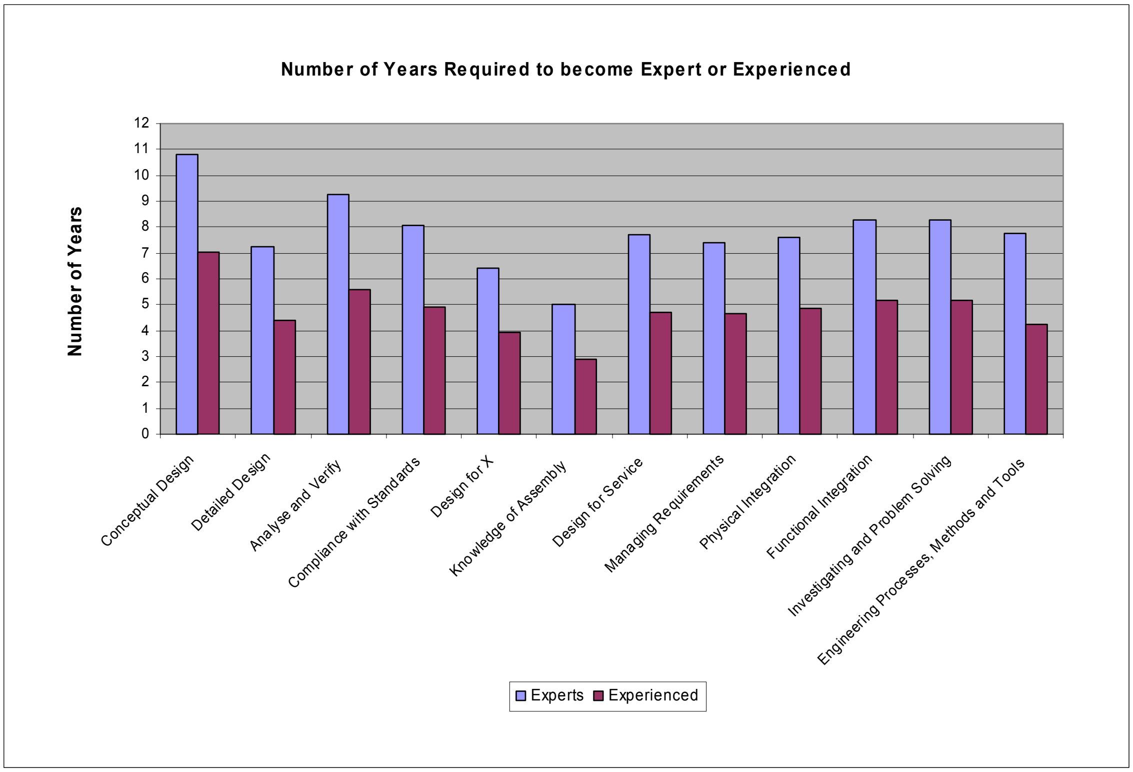

Figure 3 Process knowledge: numbers of years to become an expert or experienced

On average, it was perceived that becoming an expert in knowledge related to the product required more time than becoming an expert in knowledge related to the process (refer to Figure 4). It was perceived that 7.8 years of relevant experienced was required to become an expert in the process knowledge categories; 9.3 years for the product knowledge categories and; 10.1 years for the managerial knowledge categories. This is interesting as although it is perceived that it takes longer to become an expert in the product and their different assemblies, these are perceived as less important than knowledge of process (refer to Figure 5). One of the explanations for this maybe found from the understanding of the transfer of experience, i.e. being experienced in one particular product and then working in another product area. The knowledge acquired related to the process is the knowledge that is transferable from one product area to another, and hence it important. Although design for X, and detailed design were two of the categories perceived as the most important knowledge required for an engineering designer, becoming an expert in these types of knowledge was perceived as requiring 6.4 and 7.2 years respectively, which is not a particularly long-time in comparison to the other knowledge categories. Becoming an expert was perceived as requiring the longest period of time for the following types of knowledge: conceptual design (over eleven years), the whole engine (over eleven years) and managing resources (over fourteen years).

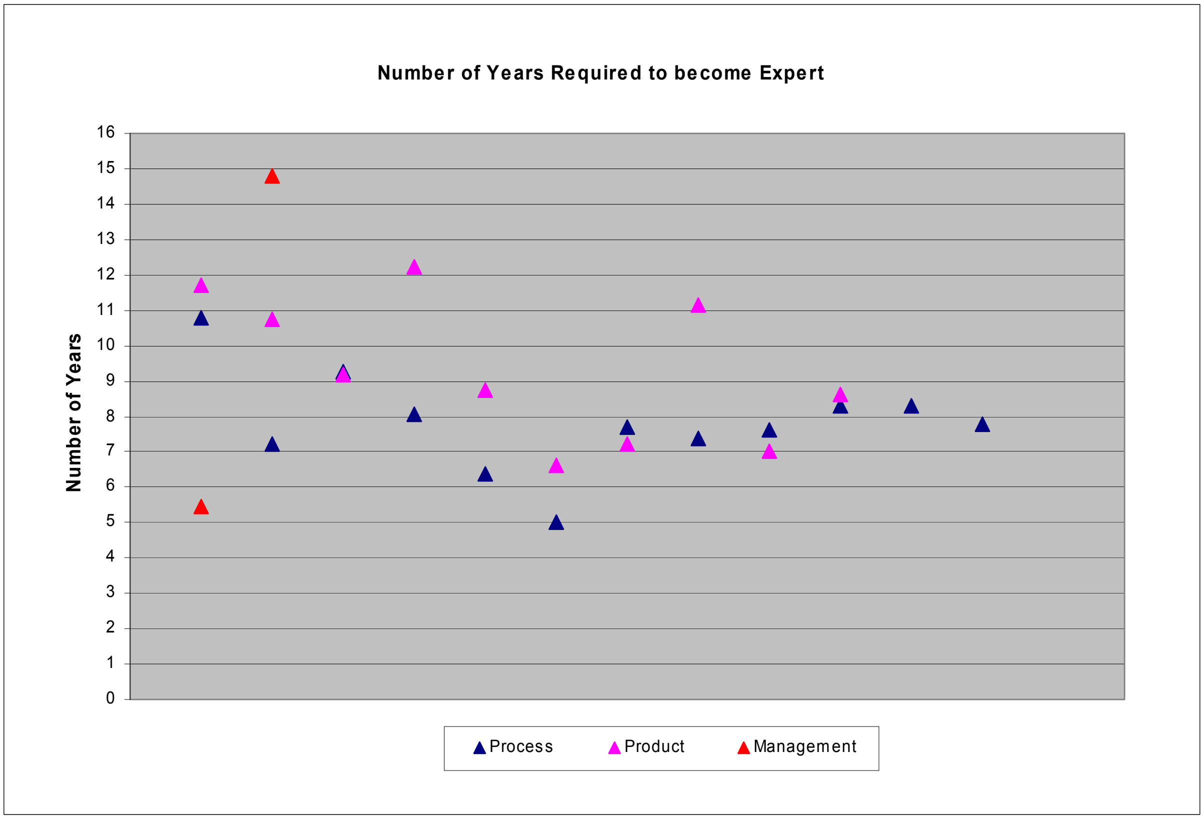

Figure 4 Number of years perceived to become an expert

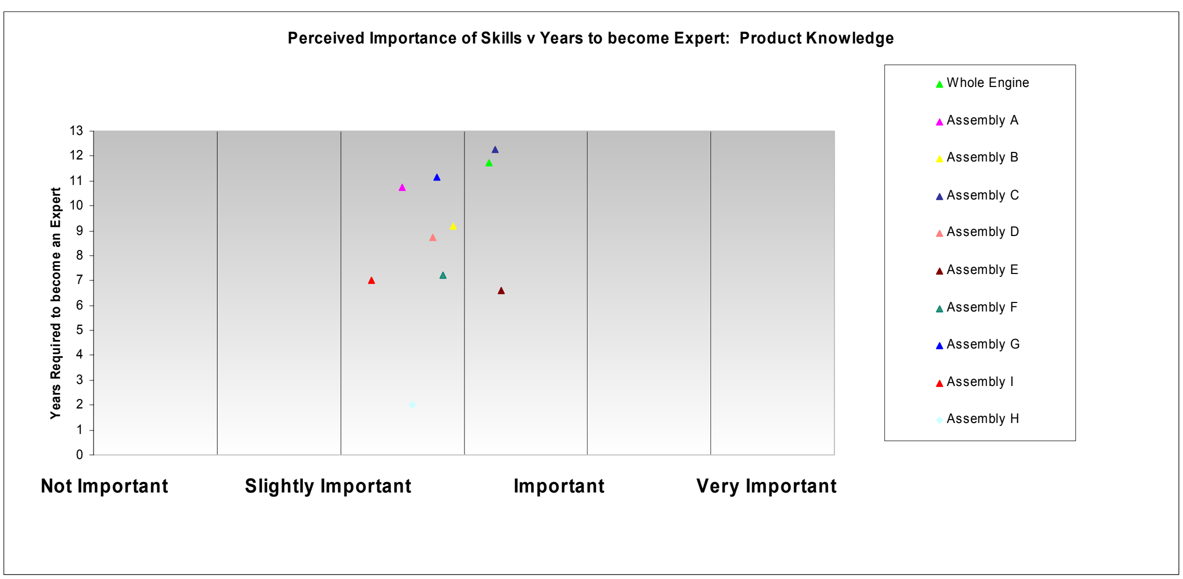

Figure 5 Perceived importance against number of years to become an expert for product knowledge

Figure 6 Perceived importance against number of years to become an expert for process knowledge

The data was analysed to understand if there was any relationship between the types of knowledge identified as important and the number of years required to become an expert in that particular type of knowledge. The perceived importance of any one category of process knowledge was found to correlate to the number of years to become an expert in that particular type of knowledge (refer to Figure 6). This was not true for the product knowledge or management knowledge.

4 Conclusions

An empirical study was conducted and the views of 26 designers were collected and analysed. The types of knowledge viewed as important currently and in ten years time for engineering designers are discussed and compared to knowledge classification in the literature. The research method employed has collected the views of twenty-six participants, and hence are only the perceptions of those involved. The seniority, level of responsibility of those involved and the number of interviews carried out increases the validity of this approach. Knowledge related to the process was perceived as more important to those related to the product, in particular knowledge for conceptual design, detailed design and designing to reduce cost or increase quality (design for X) were perceived as very important. The number of years to become an expert in product knowledge was found to be greater than for process knowledge. However, it is recognised that becoming an expert is not simply dependant on the number of years but a number of additional factors such as personal attributes.

5 Acknowledgements

This work was funded by the University Technology Partnership for Design, with industrial partners Rolls-Royce and BAE SYSTEMS. The authors acknowledge all the participants for their valuable time.

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Corresponding author:
Associate Prof. Saeema Ahmed
MEK - Engineering Design, Building 404,
Nils Koppels Allé, DK-2800 Kongens Lyngby
Tel: +45 4525 6263
Fax: +45 4593 1577
E-mail: sah@mek.dtu.dk
URL: http://www-edc.eng.cam.ac.uk/people/sa233.html