The 2nd International Conference on Design Creativity (ICDC2012)
Glasgow, UK, 18th-20th September 2012

VARIATION IN CREATIVE BEHAVIOUR DURING THE LATER STAGES OF THE DESIGN PROCESS

C. M. Snider, P. J. Cash, E. A. Dekoninck and S. J. Culley

Department of Mechanical Engineering, University of Bath, Bath, United Kingdom

Abstract: This paper presents results from an experiment studying the creative behaviour of 14 engineering designers during a later stage engineering design activity; with the aim of identifying important considerations that must be made when supporting designers in later stage design situations. Data gathered demonstrates the variation in designer behaviour that occurs even when completing identical activities; and differing creative approaches that designers may follow within the later stages of the design process. By understanding the individual behaviour of designers, it will be possible to better inform the use of methods for creative support within the later stage engineering design process.

Keywords: *creativity, designer behaviour, embodiment, detail*

1. Introduction

The importance of research into creativity is well recognised within design research, with extensive studies performed in a wide variety of disciplines. However, with few exceptions, research to date has focused on creativity in a general sense or on the earlier stages of the process, thereby excluding study into the appearance and effect of creativity and creative behaviour during later stages. Benefits within later stages have recently been identified in the field of computing (Brown 2010), and some case studies of late stage problem solving using creativity methodology exist in the engineering domain (Frobisher, Dekoninck et al. 2006).

The increase in constraint present towards the later stages of the design process (McGinnis and Ullman 1990; Howard, Nair et al. 2011), and the processes described by well-established design models (such as Pahl and Beitz (1984) or Pugh (1990)), show that the later stage design process presents a unique situation within which the designer must work. It may therefore not be sufficient to supply designers working within the later stages with the same methods of creative support as those working within the earlier stages.

To begin to address this concern, this paper presents a study focused on developing an understanding of individual designer behaviour within the later stage engineering design process, particularly the variation that exists between designers when solving identical problems. This is completed through the use of a specific creative behaviour coding framework, presented in greater detail within past work (Snider, Dekoninck et al. 2011). Through this framework the study aims to identify the importance and influence of the completed project brief on designer behaviour and preliminary evidence of differing creative approaches that designers exhibit. From this information it will then be possible to develop the understanding and direction needed for methods of creative support, which will work with the designers' inherent behaviour in an appropriate and beneficial manner.

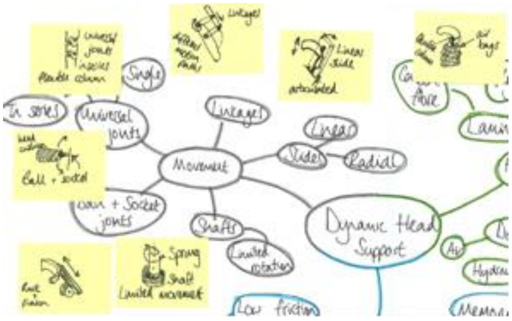
1.1 The Coding Scheme

This work uses the coding scheme presented in detail in Snider *et al.* (2011), which is designed to identify creative design approaches followed by designers during the later stages of the design process. This is achieved through study of the designers task activity throughout, specifically on the use of each task either to develop the information that they have about the design, the brief or the domain (called *information* tasks); or on the use of each task to develop the design itself as a physical product, e.g. the physical components, layouts and materials (called *application* tasks).

Each task is then defined according to its initial and final state based on information (I) and application (A), creating four possible options. Tasks in this work are defined as a transformation from either an information or application input state to a separate information or application output state, with the final classification referring to the final state of the task. For example, an information task is defined as any task that ends with an information state (see Figure 1). Designers may use the information they already have, and develop it into a broader or more developed version (I → I); they may apply the information that they have to create the design itself (I → A); they may take the current form of the design (application) and re-work it into a more developed version of itself (A → A); or they may take the current form of the design and analyse it to develop information (A → I).

In addition to these task categories, the coding scheme considers creative behaviour within each task according to whether it is completed in an *expansive* or *restrained* manner. Relating to the work of Guilford (1956), to be *expansive* refers to creativity in both divergence and convergence within the design process, through the pursuit of alternative products and technologies, or through the development and integration of new part combinations. To be restrained refers to a lack of creativity in either divergent or convergent processes. *Expansion* in a task then classifies it as *creative* within this work, while *restrained* tasks are classified as *routine*. The coding scheme identifies tasks as belonging to one of eight groups, as shown in Figure 1 according to their output entities. Throughout the work, the act of being creative in information tasks is referred to as being *astute*, and the act of being creative in application tasks is referred to as being *opportunistic*. A designer who is primarily creative in information tasks then follows an *astute approach*, while one who is primarily creative in application tasks follows an *opportunistic approach*. To provide option for further analysis, tasks are also classified according to whether their initial state is of the same type as their output state (called *single*), or of the opposite type (called *translational*).

	Information (I)		**Application (A)**	
	Single	Translational	Translational	Single
Routine	I → I	A → I	I → A	A → A
Creative	I → I	A → I	I → A	A → A



An *expansive* task performed by designer D, in which the *Function* (Dynamic Head Support) is transformed into a collection of sketches of several working principles (examples of suitable *Behaviour*). Hence the appropriate Entity Transformation and verb:

I → A; "*Expansive*"

Figure 1: The eight task types, and one example application task

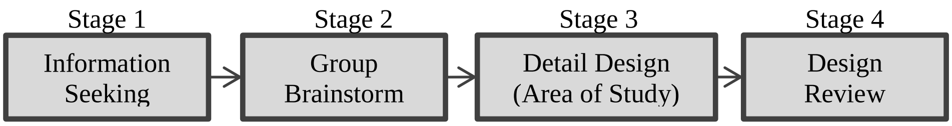
To provide illustrative example, Kevlar was originally designed as a replacement for steel within the wheels of racing cars, but has been applied to an array of applications due to its exceptional properties, ranging from body armor to loudspeaker cones. This is an example of an *astute* task, taking knowledge that already exists and applying it (with little modification) in a new context. In contrast, *opportunistic* tasks are creative through the way in which they use existing factors within the design context for new or alternative purposes, producing significant benefit. For example, through careful consideration of the configuration of components within a system it may be possible to arrange them in such a manner that some single parts are capable of completing multiple functions, or some parts are no longer needed what-so-ever. One such example could be the process of part-count reduction within design for assembly.

In addition to the coding scheme, it is necessary to categorise tasks as according to specific design stages, in order to ensure that only those typically occurring within the later design stages are included. Developing from the work of Howard (2009) and Gero (1990) this coding scheme defines design stages as according to their focus on design function, behaviour and structure. Design stages are identified according to the foci of the tasks themselves, rather than by chronology of the process (such as within Pahl and Beitz (1984)), in which later stage tasks refer to those occurring at a later point in time; or system hierarchy (Suh 1990; Ulrich and Eppinger 2012), in which later stage tasks refer to those on a lower system level. The coding scheme then includes all tasks with a focus on later stage activities regardless of when they occur, or the systems and components on which they are being completed. Within this work, later stage tasks are defined only as those concerned with producing the detailed behaviour and structure of the system, reflecting those tasks that would typically be considered as belonging to embodiment and detail stages of engineering design process models.

2. Methodology

The study was conducted on a total of 14 participants, of which two were professionals from industry with 4 and 10 years experience, two were final year undergraduate students with no direct industrial experience and 10 were final year undergraduate students with between 12 and 20 months of industrial engineering experience.

The study occurred according to Figure 2 over a period of four hours, not including supervised short breaks between stages (included to attempt to prevent fatigue and during which participants did not discuss the brief), designed to mimic a complete design process as described by Hales (1986). Breaks were not permitted between receiving the brief for a single stage and that stages completion. An extensive explanation of the methodology for this experiment is present in Cash *et al.* (2012). The brief throughout the process was to develop a remotely operated camera mount to be placed underneath a balloon for amateur aerial photography. In each stage of the experiment the designers were provided with identical sub-briefs designed to stimulate the appropriate design process activities. In each individual section, designers were working on identical sub-problems. The third stage of the study (on which analysis within this paper occurred) required the designers to "*Develop an appropriate, feasible, dimensioned, detailed solution*" from a single concept identified within the previous stage. In addition to this the designers were provided with goals that encouraged the completion of later stage tasks as opposed to early, such as "*include a description of the method of assembly*" and "*include methods of manufacture (for all components)*". Analysis only included tasks defined as occurring within embodiment and detail stages, any conceptual tasks that occurred were excluded. All analysis within the study considers only the designers as individual workers, as they were within the studied experimental stage. While the importance of the influence of working within teams in prior stages is recognised, such analysis is beyond the scope of this paper and will be considered in further work.



Duration	50 mins	50 mins	90 mins	50 mins
Teamwork	Individual	Group	Individual	Group

Figure 2: Structure of the Study

In addition to these stages each participant completed a detailed background questionnaire, a creative style test similar to the KAI test (Kirton Adaption-Innovation (Kirton 1976)), and the Torrance Tests of Creative Thinking (TTCT) Figural Form A (Torrance 2008) to determine personal creative level.

Within each individual stage designers were given identical specific instructions to stimulate tasks that match those that would occur in a realistic design setting. The third stage of the experiment, labelled "Detail Design" was specified such that it would require detailed design tasks typically found within the later stages of the engineering design process, defined according to Section 1.1 above. As only the third stage concerned later stage, individual design, it was the only stage included in the analysis presented in this paper. Further analysis regarding other stages of the experiment is ongoing.
Within each section of the study, data was collected through the use of webcams to capture the designer, Panopto software (www.panopto.com) to capture their use of computers, and LiveScribe (www.livescribe.com) notebooks and pens to capture their individual use of logbooks in detail, including an accurate measurement of time of occurrences. Through this comprehensive method of data collection it was possible to perform detailed analysis of designer behaviour over time.
Individual tasks were coded for each designer according to the scheme summarised in Section 1.1 by a single researcher, through careful analysis of markings within logbooks and computer use against time of occurrence. Coding of the work of each designer was completed in a single sitting to ensure continuity of coding standards. Only those tasks that were determined to be within the later stages were included in the analysis. Although no inter-coder reliability analysis was carried out in this case, the coding scheme has previously demonstrated a value for Krippendorff's alpha (Hayes and Krippendorff 2007) of $\alpha = 0.768$ on a similar data set (Snider, Dekoninck et al. 2011), a value that is suitable for exploratory work of this form (Blessing and Chakrabarti 2009).

3. Results and Discussion

In total, the 14 designers completed 130 tasks that were classified as later stage design tasks, with an average of 9 and range of 5 to 18 tasks per designer. All tasks within the third stage that were judged as conceptual were excluded from analysis; data within this work refers only to those tasks within the embodiment or detail stages, defined in this work as later stage.

3.1 The influence of the project brief on designer behaviour

Through comparison of the behaviour of the designers while completing the project it is possible to gain some understanding regarding the influence of the brief itself, and hence whether the larger influence on designer behaviour stems from the nature of the work that is being completed or from the individual approach of the designer themselves.

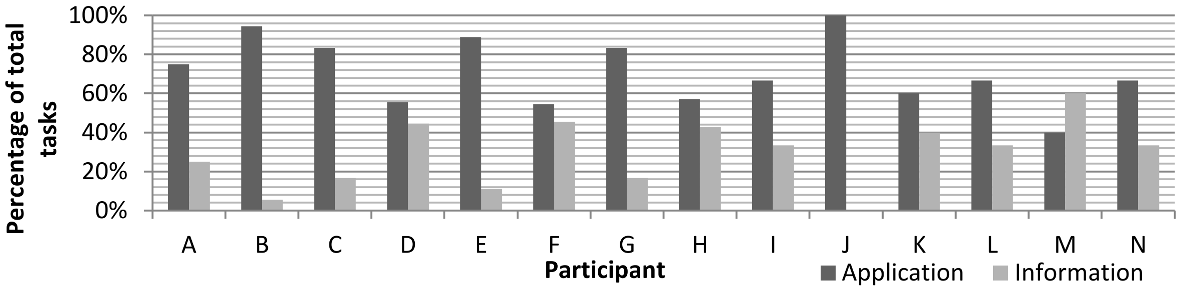


Figure 3: Proportions of information and application tasks

Despite being provided with identical briefs and instructions throughout the study, the behaviour of the designers within the third section varied greatly. While some (such as Designers D, F, H and M) completed a large proportion of information based tasks, others (particularly Designers B, C and J) almost entirely based their work in application. Therefore, while the former designers spent some time developing their knowledge of the task, other designs and alternatives within the domain; the latter designers developed ideas through manipulation of the design as it appeared following the group brainstorm session, with little additional input through information searching or development.
Particularly interesting is the variation in behaviour between designers. Previous work (Snider, Dekoninck et al. 2011) within a longitudinal study in which seven designers completed differing briefs highlighted a similar spread of difference in designer behaviour (Figure 4). That a difference in

behaviour exists regardless of whether the designers complete different or similar briefs suggests that the primary influence is not the brief itself, but is rather the designer and their approach or style.

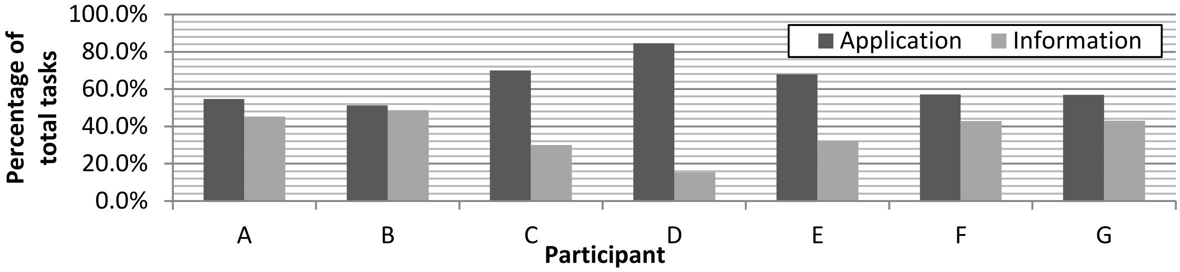


Figure 4: Information and application task proportions from past work by Snider *et al* (2011)

3.2 Variations in creative behaviour

There are some consistent trends present between designers relating to the type of tasks that they complete, and those in which they are creative, according to the data shown in Table 1. Statistical significance for findings was assessed using the Wilcoxon signed-rank test.

Designers tend to favour application output tasks ($p = 0.002$; designer average 75.4% application output tasks; Table 1, columns 1,2), and single tasks when working in later stages ($p = 0.0076$; designer average 63.8% of single output tasks; Table 1, columns 5,6). Then looking at the creative behaviour of designers within both single and translational tasks, there is a preference for a higher proportion of translational tasks to be performed creativily ($p = 0.0054$; average proportional translational expansion 34.3%; average proportional single expansion 15.1%; Table 1, columns 5,7).

Table 1: Percentage tasks within selected categories

	Information / Application split (proportional to total tasks)				**Single / Translational split (proportional to single/translational category)**			
Designer	**Application Output Tasks (%)**		**Information Output Tasks (%)**		**Single Output Tasks (%)**		**Translational Output Tasks (%)**	
	Single	Translational	Single	Translational	Expansive	Restrained	Expansive	Restrained
A	25.0	50.0	12.5	12.5	33.3	66.7	40.0	60.0
B	72.2	22.2	0.00	5.56	15.4	84.6	40.0	60.0
C	58.3	25.0	8.33	8.33	25.0	75.0	75.0	25.0
D	22.2	33.3	44.4	0.00	33.3	66.7	33.3	66.7
E	50.0	38.9	0.00	11.1	11.1	88.9	22.2	77.8
F	36.4	18.2	27.3	18.2	14.3	85.7	50.0	50.0
G	50.0	33.3	16.7	0.00	25.0	75.0	50.0	50.0
H	42.9	14.3	28.6	14.3	20.0	80.0	50.0	50.0
I	22.2	44.4	22.2	11.1	0.00	100	20.0	20.0
J	90.0	10.0	0.00	0.00	0.00	100	0.00	100
K	40.0	20.0	20.0	20.0	0.00	100	0.00	100
L	50.0	16.7	33.3	0.00	0.00	100	0.00	100
M	20.0	20.0	40.0	20.0	33.3	66.7	50.0	50.0
N	33.3	33.3	33.3	0.00	0.00	100	50.0	50.0
Mean	**43.8**	**27.1**	**20.5**	**8.60**	**15.1**	**84.9**	**34.3**	**65.7**
S.D.	**19.5**	**11.5**	**14.4**	**7.52**	**13.0**	**13.0**	**22.1**	**22.1**

That designers favour single tasks but are more creative within translational tasks suggests possible directions for creative support, and for the enhancement of creative behaviour within the later stages of the design process. Stimulating designers to perform tasks that switch between information and application rather than stay within one or the other may enable them to follow a more creative process due to the potential creative properties of translational tasks.

3.3 Differences in creative approach in later stage design tasks

While a strong similarity exists between designers in terms of the focus of their tasks and the appearance of creative behaviour in tasks that transfer from information to application or vice versa, differences appear when looking at creative behaviour against type of task output.

Although the majority of tasks within the later stages consistently focus on application output tasks across designers, the form of task in which they are expansive varies. While Designers A, B, D, E, I, M and N all performed a higher proportion of application output tasks expansively (proportional average 23.7% more application); Designers C, F, G and H all performed a higher proportion of information based tasks expansively (proportional average 30.4% more information, See Figure 5).

This difference corroborates that found in past work (Snider, Dekoninck et al. 2011), and demonstrates both the varying ways in which designers may be creative, and that varying preferences for each exist. Furthermore, it agrees with the definitions for creative processes presented by other researchers (see Dym (1994)). The *astute* designer is one who is creative primarily through the information that they gather throughout the process, searching for alternative solutions, functions or features that could be incorporated into their design and then directly applying them to their work.

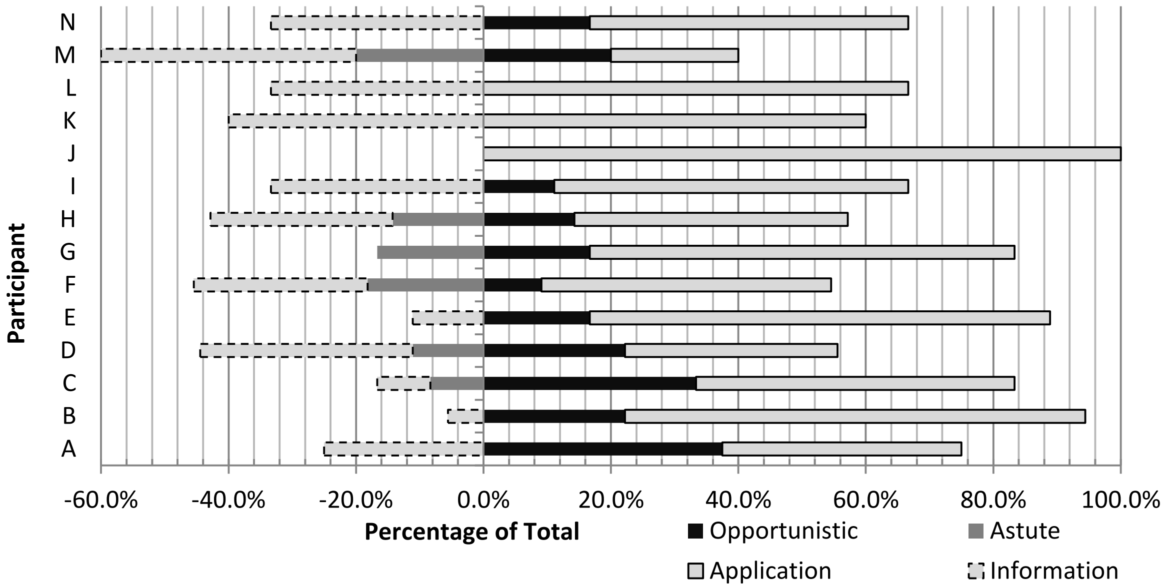


Figure 5: Proportions of information and application tasks, and expansion within each

3.4 Correlations between data and external creative tests

In addition to the main study, the designers also each completed a creative style test similar to the KAI test (Kirton 1976), and the TTCT test (Torrance 2008) to determine creative level. The results from each of these were then used to identify correlations between the collected data and these external, accepted measures of creativity, shown in Table 2.

Table 2: Correlations found within the data

1st Variable	2nd Variable	Correlation	Significance (p<…%)
Overall expansion	*Single* expansion	0.919	0.0166
Overall expansion	*Opportunistic* expansion	0.903	0.0486
Creative style test	Overall expansion	0.617	0.940
Creative style test	*Opportunistic* expansion	0.596	1.22
Translational expansion	TTCT Creative level test	0.427	6.39

That correlation exists between overall expansion within tasks and expansion within the *single* and *opportunistic* categories is not surprising; interest does however lie in the particular strength of these correlations. That designers who are expansive in single tasks (shown to be a less common trait; Table 1) are more expansive overall perhaps demonstrates an inherent creative ability; should you be more creative in tasks that are typically routine, you are more likely to be creative overall. Similarly, as *opportunistic* expansion is more common than *astute* (Figure 5) and therefore provides a larger contribution to overall expansion, this is perhaps an area of focus for the development of creative support. Should *opportunistic* expansion be more suitable within the later stages of the design process then tools should be tailored more towards its stimulation.

That significant correlation exists between the creative style test and overall expansion demonstrates a link between the results produced by the coding scheme and an external measure of creativity. Those that are more expansive are then similar to those identified as creative *innovators* within the test, a creativity style that is described as bearing a higher resemblance to typical views of higher creative level within the literature (Kirton 1976). The lack of significance between the data and the TTCT suggests that those who are more expansive are not necessarily those judged by the TTCT to have the highest creative level. Within this work the focus is not to capture those that produce the most creative results, but rather to identify creative behaviour within the later stages of the design process. The data does not then judge level of creativity, only those behaviours that increase the potential to achieve a creative result of some form. Correlation against creative level is not directly expected; that some designers may require a significant amount of creative behaviour to achieve a moderately creative result and some may require little creative behaviour for a highly creative result is a trait of the extent of their inherent creative ability, and not of their style within the process. Through future work this link can be studied in more detail; identifying the practices of those who have an inherently high creative level and whose work correlates with beneficial end results may highlight ways in which the creative design process can be made more efficient.

4. General Discussion

Of particular interest and implication for the support of designers within the later stage engineering design process is the knowledge that behaviour will vary independent of the brief; designers will follow their own creative approach, showing a preference for the types of task that they complete and for those in which they are expansive.

Considerations for creative support must then take this into account. While one tool may be particularly applicable for one designer in a specific situation, the frequently used assumption that a tool will be suitable for all designers in that situation or indeed for the same designer in any other situation cannot be made. While certain trends and preferences exist between designers, such as a predominance of application based tasks and translational expansion (Table 1), designer support must also take into account those aspects of designer behaviour that are not always shared. Tools or techniques could be proposed to enhance creative behaviour in a manner that is compatible with the designers' inherent style; thereby providing creative support which improves process efficiency or product value without the potentially stifling effect of encouraging designers to use tools that do not match the way in which they would naturally work.

One aspect that has not been studied in detail to date is the overall creative level or final value of the designs produced. As such, it is currently not possible to state the exact form that creative tools or techniques should take. For example, while more designers seem to follow an *opportunistic* approach (Figure 5), it is not known whether this approach is preferable to an astute approach in terms of benefit. As such it is not logical to suggest the development of tools that encourage *opportunistic* behaviour; it is equally possible that those who are naturally *opportunistic* would benefit from enhancement of *astute* characteristics as it is that they would benefit from further support of their own natural style. Further work is then required on the benefits of these particular types of creative behaviour and of the effect on their manipulation.

5. Conclusions

The work presented in this paper has demonstrated the differences that exist between designers while working at the later stages of the engineering design process, particularly looking at behaviour that is deemed creative. While some designers primarily develop new ideas and alternatives through the use and discovery of new information concerning the design and brief; others primarily develop ideas through the way in which information is applied to the design itself, and how the form and arrangement of components can be manipulated. This behaviour exists irrespective of whether the designers are working on the same brief individually or on different briefs. Their behaviour is therefore likely a product of their own approach rather than of the design brief itself.

This study also reveals some directions for further research, which in turn will impact the development of creative support methods. It cannot be assumed that, given the present differences in behaviour, all forms of creative support will be appropriate and beneficial to all designers while they are working in the later stages. Similarly, it cannot be assumed that those tools which are commonly used and proven within early design stages are equally effective within the later stages. It is therefore important that both of these factors are taken into account when developing methods of creative support, which will lead to more beneficial end results.

6. Acknowledgements

The work reported in this paper has been undertaken with support from the Engineering and Physical Sciences Research Council's (EPSRC) Innovative Design and Manufacturing Research Centre (IdMRC) at the University of Bath (grant reference EP/E00184X/1)

References

Blessing, L. and A. Chakrabarti (2009). DRM, a Design Research Methodology. London, Springer.

Brown, D. C. (2010). The Curse of Creativity. DCC10: the 4th International Conference on Design Computing and Cognition, Stuttgart, Germany.

Cash, P. J., B. J. Hicks, et al. (2012). A comparison of the behaviour of student engineers and professional engineers when designing. DESIGN 2012: 12th International Design Conference, Dubrovnik, Croatia.

Dym, C. L. (1994). Engineering Design: A Synthesis of Views, Cambridge University Press.

Frobisher, P., E. A. Dekoninck, et al. (2006). Improving Manufacturing and Process Innovation at an Automotive Component Manufacturer. IDMME 2006: International Conference on Integrated Design and Manufacturing in Mechanical Engineering, Grenoble, France.

Gero, J. S. (1990). Design Prototypes: A Knowledge Representation Schema for Design. AI Magazine. **11:** 26-36.

Guilford, J. P. (1956). "The structure of intellect." Psychological Bulletin **53**(4): 267.

Hales, C. (1986). Analysis of the Engineering Design Process in an Industrial Context. Department of Engineering. Cambridge, University of Cambridge. **PhD**.

Hayes, A. F. and K. Krippendorff (2007). "Answering the call for a standard reliability measure for coding data." Communication Methods and Measures **1**(1): 77-89.

Howard, T. J., S. J. Culley, et al. (2009). The Integration of Systems Levels and Design Activities to Position Creativity Support Tools. ICoRD '09: International Conference on Research into Design. Bangalore, India.

Howard, T. J., V. V. Nair, et al. (2011). The Propagation and Evolution of Design Constraints: A Case Study. ICoRD '11: International Conference on Research into Design, Bangalore, India.

Kirton, M. (1976). "Adaptors and innovators: A description and measure." Journal of applied psychology **61**(5): 622.

McGinnis, B. D. and D. G. Ullman (1990). "The Evolution of Commitments in the Design of a Component." Journal of Mechanical Design **114**: 1-7.

Pahl, G. and W. Beitz (1984). Engineering Design: A Systematic Approach. London, Springer.

Pugh, S. (1990). Total Design: integrated methods for successful product engineering. Harlow, Prentice Hall.

Snider, C. M., E. A. Dekoninck, et al. (2011). Studying the appearance and effect of creativity within the latter stages of the product development process. DESIRE'11: The 2nd International Conference on Creativity and Innovation in Design. Eindhoven, Netherlands.

Suh, N. P. (1990). The principles of design. Oxford, UK, Oxford University Press.

Torrance, E. P. (2008). Torrance Test of Creative Thinking: Norms-Technical Manual Figural (Streamlined) Forms A & B. Bensenville, IL, Scolastic Testing Service Inc.

Ulrich, K. and S. D. Eppinger (2012). Product design and development. New York, McGraw-Hill.