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The appearance of creative behaviour in later stage design processes

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Abstract:

Creativity is widely seen as an important subject in the study of the engineering design process. Through analysis using a previously presented framework and coding scheme, this paper presents two studies on creative designer behaviour within later design stages. Through the studies, one being longitudinal and the other a laboratory experiment, two creative approaches have been identified based on whether designers are more often creative when developing the knowledge and variables available for the design, or the design output itself. This individual difference correlates significantly with the designers' creative style as measured by an independent creative style test. This data demonstrates the variation in designer behaviour that appears even when completing identical tasks. By understanding the creative behaviour and approaches followed by designers, it will be possible to develop specific and particularly appropriate methods of designer support, dependent on the stage of the design process and particular approach of the designer.

Keywords: creativity; design; behaviour; embodiment; detail

The appearance of creative behaviour in later stage design processes

1. Introduction

Creativity is an important subject of study within design, as can be seen through the wide body of literature within fields such as architecture (Akin & Akin, 1996), computer science (Brown, 2010), human-computer interaction (Shneiderman et al., 2006) and engineering design (Howard, Culley, & Dekoninck, 2008). Typically, a creative product is defined as novel within the context of its field or market and suitable as a solution to the presented problem, through terms such as *novelty* and *appropriateness* (Chakrabarti, 2006; Howard et al., 2008; Sternberg & Lubart, 1999).

It is very important when studying creativity to consider not only the creative product that forms the design solution, but also to consider the other three elements contributing to creativity as proposed by Rhodes (1961); the person who is being creative (Feist & Barron, 2003), the process that they are following (Cross, 2004a) and the environment in which they are working (referred to as the creative “press”) (Csikszentmihalyi, 1999; Lubart, 1999), shown in Figure 1.

Much valuable work has been undertaken on the subject of creative *products* and their identification (Sarkar & Chakrabarti, 2011; Shah, Smith, & Vargas-Hernandez, 2003), however when considering creativity research, the other elements must also be considered. This is the contextual framework for the work presented in this paper. This paper will analyse the approaches that designers choose to employ throughout their design process as they create a product, with an aim of identifying commonalities and enhancing understanding of creative approaches and typical patterns of behaviour within design process stages. In this way, the pillars of the creative person, creative process and creative product are considered. Although an important subject for creativity research, consideration of such in the context of the creative press is considered beyond the current scope of this work, and will be the focus of future research.

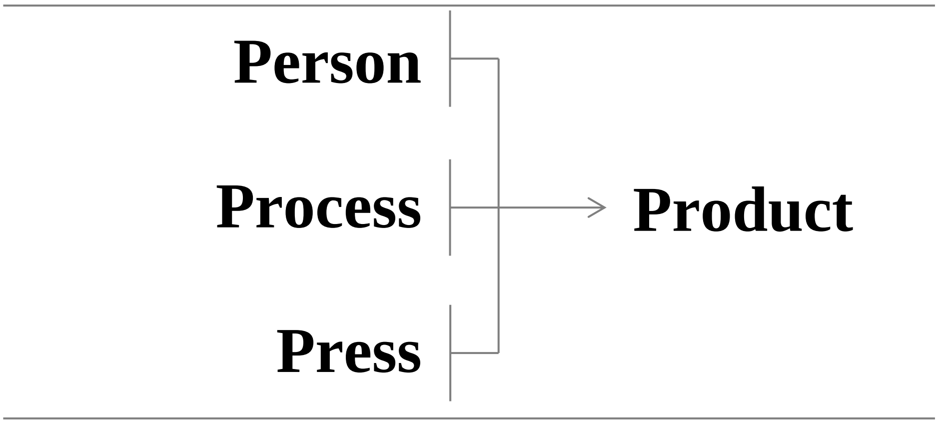

Figure 1: The structure of the four pillars of creativity; Rhodes (1961), adapted from Samuel et al. (2011)

The next contextual setting is the timing. Whilst a significant body of work has focused on creativity within early and more open stages, it has been shown that many design processes focus on incremental change (C. Eckert, Stacey, Wyatt, & Garthwaite, 2012), adaptive change, or variant design (Pahl & Beitz, 1984). These are often considered to take place in the later and more detailed stages of design (Howard et al., 2008). The increased levels of constraint (Howard, Nair, Culley, & Dekoninck, 2011; McGinnis & Ullman, 1990), and the higher impact of change within later design stages (C Eckert, Clarkson, & Zanker, 2004), make this a very important and difficult area for designers. Thus the study of the design process and creative process within these later stages represent an important specific design situation, which is currently under-researched.

It is the purpose of this paper to present the results from two studies into the individual creative approaches employed by designers within the later stages of the engineering design process, their behaviour, and the types of task that they complete. Through comparison of the results from these two studies, which demonstrate many methodological differences, the paper identifies significant commonalities in designer behaviour, allowing the development of understanding of creative approaches employed by designers within later design stages. As part of this research it was necessary to establish a consistent research framework and associated coding scheme. This underpins the methodology. These are described in some detail in the next two sections and use two sets of data, drawn from the analysis of logbooks and then some experimental work. By considering and analysing both sets of results in tandem, it is possible to see the appearance of creative approaches that appear within later stage design.

The critical underpinning research elements, namely the coding scheme and methodology, are described in detail in the next sections.

2. The Research Framework and Coding Scheme

The research within this paper has been completed through the use of a framework and coding scheme designed specifically to identify different types of creative task within individual designer processes (Snider, Culley, & Dekoninck, 2013). Through highlighting the importance and role of individual *tasks* completed by the designer, the framework and coding scheme are presented here in order to show how the subsequent research is enabled. This work aims to develop understanding of creative behaviour through a quantitative study of the patterns seen in the task types completed, and specifically in the behaviour of designers completing typical tasks within later design stages. Quantitative studies are widely used (Blessing & Chakrabarti, 2009) and have produced much interesting and valuable work within the field of design research (e.g. (Ahmed, Wallace, & Blessing, 2003; Atman, Chimka, Bursic, & Nachtmann, 1999; Christiaans & Venselaar, 2005; Yilmaz & Seifert, 2011)). It is through the degree to which certain creative approaches appear in the context of the types of task that are completed and the design situation and stage that this work aims to gain understanding of typical creative approaches, with an eventual goal within further work of improving methods of designer support.

2.1 Types of task

Tasks within this work are defined as equivalent to *actions* within Activity Theory (Kaptelinin, Kuutti, & Bannon, 1995); as discrete elements of the designers' individual process with a specific goal. At a higher level, through a series of tasks the designer will complete *activities*, defined as a discrete element of the design process itself with a specific goal. By classifying the variation in *tasks* that different designers use to complete *activities*, the framework aims to identify the differing *approaches* used by designers to complete identical goals. *Approach* within this work is defined as the sequence of *tasks* performed by designers, to complete a single or series of design *activities*.

Based on the work of Gero (2000) and Dym (1994), the framework proposes that all tasks completed by designers can be classified as either concerning the knowledge and variables present for the design to occur (termed *information* focused tasks), or as concerning how that knowledge and those variables can be applied and used within the design (termed *application* focused tasks).

Both information focused and application focused tasks can be carried out in a *non-creative* or *creative* manner. This gives four different types of task in total; two of which are *non-creative*, and two of which are *creative*.

As according to the definition above, the sequence of tasks completed by a designer to progress through design activities indicates their approach. Different patterns or predominant types of task in the activities of different designers then indicate different approaches. As such, a significant predominance in any of the four types of task indicates a different approach. Should a designer be more often creative when completing *information* focused tasks (termed *astute* tasks), they are classed as following a predominantly *astute* approach; should a designer be more often creative when completing *application* focused tasks (termed *effectuating* tasks), they are classed as following a predominantly *effectuating* approach. The existence of these two approaches is evidenced in previous work (Snider, Cash, Dekoninck, & Culley, 2012; Snider et al., 2013), and is further supported within this paper. When a designer is more often *non-creative* when completing information focussed tasks (termed *regular* tasks) or application focussed tasks (termed *standard* tasks), their approach is referred to as predominantly *regular* or *standard* respectively.

The terms *astute*, *effectuating*, *regular* and *standard* are proposed for use in this framework and coding scheme to provide distinction between different types of task and different approaches, and are not extracted from literature. These terms, in relation to their creative properties and task focus, are shown in Table 1.

Table 1: The four task types, defined through their focus and creativity

	Non-creative	**Creative**
Information focus	“Regular”	“Astute”
Application focus	“Standard”	“Effectuating”

As example, an *astute* approach will primarily entail *astute* tasks such as the identification or creation of new knowledge or variables that can be used for design (such as a new material or manufacture process); an *effectuating* approach will primarily entail *effectuating* tasks such as the use of current knowledge or variables in a new way (such as reducing the number of parts used in a sub-system). A *regular* approach will primarily entail the gathering of knowledge regarding the variables that are already present (such as clarification of previously used material properties), and a *standard* approach will primarily entail the use of current knowledge and variables in a known way (such as configuration of a layout based on past iterations). It is therefore the summation of types of task that indicate the predominant approach that the designer has chosen to take.

2.2 Expansion as an indicator of creative tasks

Within this work, whether a task is completed in a non-creative or creative manner is judged through whether the task contains evidence of *expansion*, a term illustrated in Figure 2. This term has been developed from literature, as described below, and forms part of the coding scheme for experimental work.

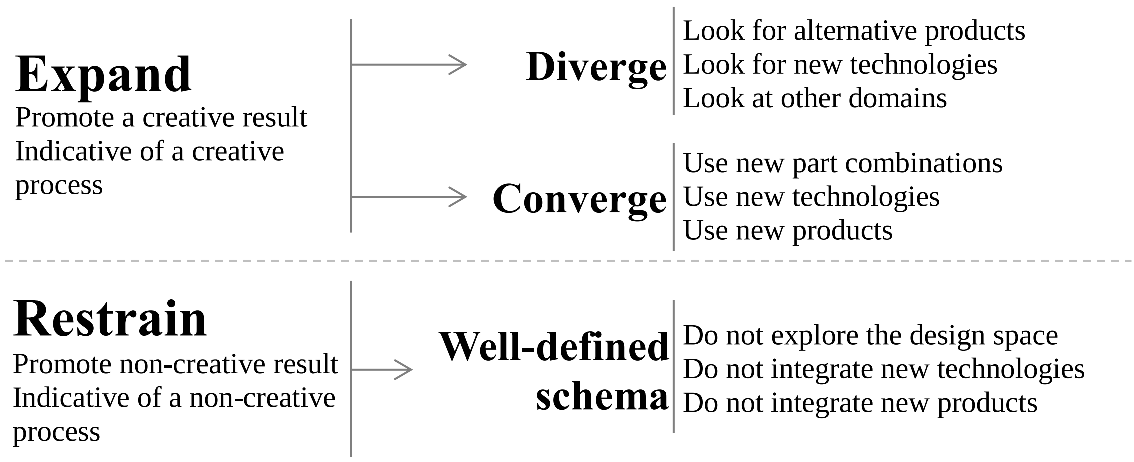

Figure 2: Expansion and restraint as terms describing non-creative and creative

Expansion refers to the active process applied by the designer of attempting to uncover new options for their design process. Within the context of *information* and *application* focused tasks, this manifests in the attempt to identify new and appropriate knowledge or variables that can be used for *information*; and the attempt to identify new and appropriate ways of applying the current knowledge or variables for *application*. In this sense, expansion is characterised by the active attempt to produce the option for a novel and highly appropriate product to be produced, mirroring the accepted definitions of creative products (Howard et al., 2008; Sternberg & Lubart, 1999). Relating to the classical view of Guilford (1956), expansion relates to creativity both in the divergent and convergent stages of the process. While in divergence (when exploring the design space and identifying alternatives) creative behaviour is logical; however, convergence can also be creative (Cropley, 2006) through the use of alternative combinations of parts and systems, or evaluation through criteria such as functionality beyond that originally specified.

As discussed in much research, the creative behaviour of any designer is in no small part dependent on their personality, training and experience (Christiaans & Venselaar, 2005; Feist, 1999; J. R. Hayes, 1989). The design approaches taken by designers and identified within this work are considered a result of this; ultimately the specific creative behaviour of each designer stems from factors such as their background and personality.

It should be noted that this work places a distinction between the completion of a creative process, and the production of a final creative output. It is thought that while producing a creative output will require the completion of creative tasks; expansion and the completion of creative tasks do not require or guarantee the production of a creative output. For example, should a non-creative solution be of higher feasibility or lower cost, it is possible that they will be chosen over a creative alternative. This work does not then look only at the creativity of the output for indication that a creative process has taken place, studying instead at the tasks completed by designers and whether they were completed in a creative manner.

2.3 The framework for research

This research then uses the framework illustrated in Figure 3, in order to code tasks completed by designers throughout their design process.

Coding of tasks occurs using a scheme presented in detail in previous work (Snider et al., 2013) and briefly summarised here. First, individual tasks are identified according to the MOKA methodology (Stokes, 2001), based on the transformation of input and output entities within. Each task is then judged as either *non-creative* or *creative*, based on evidence of expansion (Section 2.2). By analysing the entities present, each task is classified as either focusing on *information* or focusing on *application*. An *information* focused task relates to the development of knowledge and variables available for the design, while an *application* focused task relates to the way in which knowledge or variables are applied to the design (generally in terms of the design output at its current state).

This process gives a full breakdown of the tasks completed by each designer; whether they are *non-creative* or *creative*, and whether they are of *information* or *application* focus. Hence creative *information* focused tasks (*astute* tasks) and creative *application* focused tasks (*effectuating* tasks) can be identified, and the approach of the designers can be characterised.

Within the scheme, it is the predominance of either astute or effectuating tasks over the other that characterises the designers' approaches. Should a large majority in either appear, it signifies a predominant approach taken by the designer. Variation in approach between designers then signifies whether their creative behaviour is a result of the projects being completed, or a result of an inherent preference or style of the designer themselves. Further, correlation of these approaches with external measures of creative style provides evidence of validity.

It should be noted that the predominance of one approach over another is variable; depending on the proportions of astute and effectuating tasks that appear, the designers will be characterised as having a stronger or weaker preference for one approach over the other. A two-dimensional spectrum such as this has been used for the characterisation of creative style in other work (see M. Kirton, 1976).

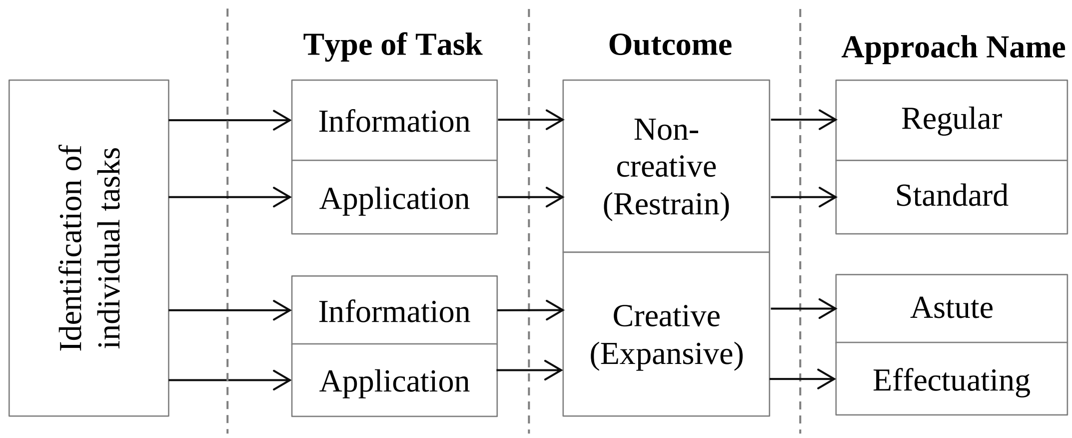

Figure 3: The framework for analysis

2.4 Classifying data for analysis

Analysis with this framework primarily occurs by classifying tasks as above. However, an alternative method is thought to produce useful results. Information and application focused tasks as described classify by output – whether the task is producing developed knowledge or variables (information focused), or producing a design using them (application focused). As the coding scheme methodology classifies the focus of both the input and the output of each task (as according to the MOKA methodology), it is also possible to classify tasks by whether focus remains constant throughout the task, or shifts from one area to the other.

Should focus remain constant throughout the task, the designer is solely attempting to develop the knowledge or variables within the design (if information focused), or is solely developing the design itself (if application focused). This is referred to in this work as a *within entity* task. Should focus at the offset of a task be on the development of knowledge or variables, and at the end be on how they can be applied to the design (information focus to application focus); or at the offset be on the development of the design itself and at the end be on how the design informs the knowledge and variables present (application focus to information focus); then the task is referred to as a *cross entity* task. The term *entity* is used here in reference to the vocabulary used in the MOKA methodology. This framework is shown in Figure 4.

Examples of a *within entity* task could be the clarification of material properties (information focus), or the dimensioning of non-critical components (application focus). Examples of a *cross entity* task could be re-configuration of a component (application output) based on additional manufacture requirements (information input); or the re-assessment of specifications values (information output) following a prototyping stage (application input).

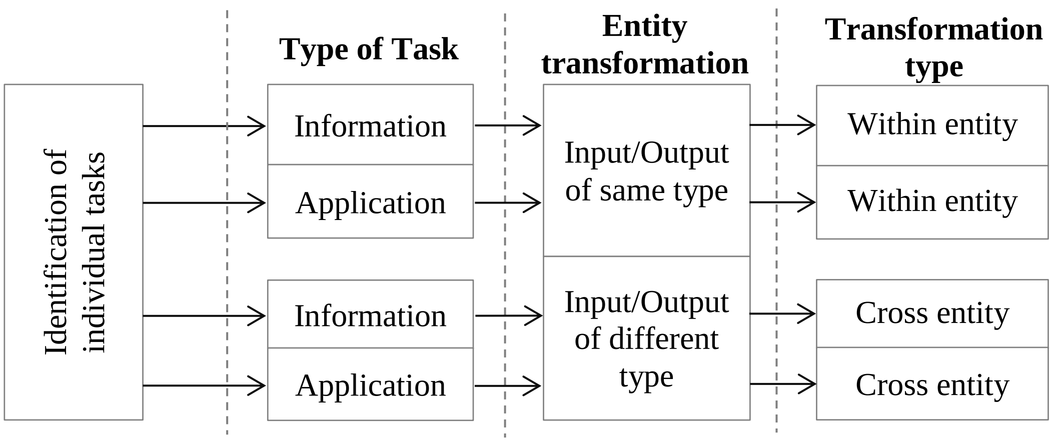

Figure 4: Identification of types of entity transformation

When coding, tasks are identified and classified directly by identifying entities within the data. It is for the coder to decide whether the appearance of an individual entity is a task input or task output and the type of transition between; a latent pattern data coding process (Potter & Levine Donnerstein, 1999). Every task is therefore evidence based within the data, identified sequentially and directly according to their input and output in the context of the design problem and stage of the design process.

Granularity of tasks within the data is defined by the entities present, it is a requirement of the scheme that every entity is coded as either part of a task input or output and as such tasks are identified according to the highest level of detail present. Although further decomposition of tasks is possible (similar to the decomposition of actions to the level of cognitive processes within Activity Theory (Kaptelinin et al., 1995)) this is considered future work.

2.5 Definition of the stages of design

Following the work of Howard *et al.* (2009), this work understands that a complete design process as presented by many processes models (Cross, 2000; Pahl & Beitz, 1984; Pugh, 1990) can occur individually on any system, sub-system or component within a design, as part of a much larger design process. It is therefore important that definition of design stages is not considered as only chronological (where prior to one point all tasks belong to a different stage as after), or only hierarchical (where design of higher level systems is considered early stage while design of detailed components is considered later stage). This work defines design stages based on the types of activities taking place, similar to Howard (2008), Gero (1990; 2004) and Duffey and Dixon (1990), as in Table 2. According to Gero and Kannengiesser (2004), the design process begins with a process of developing function and knowledge in order to formulate expected system behaviour. Within this work, these are primarily considered concept tasks. Following, actual system behaviour is synthesised from the developed solution principle, and compared to the expected behaviour. These are primarily embodiment tasks as defined within this work. Once this is complete the system structure is finalised and documented, primarily detail tasks within this work.

Table 2: Definition of design processes stages

Design Stage	Activity Definition
Analysis	Determine the required and desired functions of the system, for it to complete its purpose.
Concept	Conceive the system functions in detail through preliminary description of system behaviour.
Embodiment	Design detailed system behaviour through preliminary description of system structure.
Detail	Design and finalise system structure, and all other concerned aspects.

Typically, research into creativity has occurred in a general sense (for example, (Dorst & Cross, 2001; Gero, 1996)) or in the context of the earlier design stages (for example, (Nguyen & Shanks, 2009; Shai, Reich, & Rubin, 2009)). The focus of this work is on the less-researched stages defined here as embodiment and detail, and henceforth referred to as *later stages*.

Thus, in this work, later stage tasks are defined as those in which focus lies on developing the detailed behaviour of a system or sub-system through the development of system structure, and the subsequent development and finalisation of components. In all such cases detailed functional structures of the system and sub-systems have been decided, as have primary system and sub-system behaviours. At these stages tasks do not typically focus on radical or original design problems; but design problems within the bounds of an already developed design space. However, this work argues that creative behaviour does still occur at these stages, both within the typical forms of design problem and in the form of original or radical design when designers are capable of performing such within a developed design space, or the additional benefits and design situation warrant re-development of previous design decisions.

3. Methodology

Using this framework, the approaches of 19 designers in total were analysed from two separate studies.

3.1 Procedure (Study 1)

The first study was a longitudinal analysis of 7 undergraduate trainee engineers at the University of Bath over a 22 week individual project. Participants had an average of 5 months industrial engineering experience, and were selected from a total population of 17 on a final year specialising design course. Although completing different projects, each designer progressed through the typical stages of the design process, from initial task clarification to building a physical proof-of-principle prototype. The project structure is shown in Table 3.

Table 3: Project procedure ***(study 1)***

Weeks 1-11	Weeks 12-22
Stage 1 Develop problem understanding Stage 2 Perform background research and develop initial concepts Stage 3 Report research and in-depth specification	Stage 4 Develop final concept Stage 5 Manufacture proof of principle working prototype Stage 6 Full report
Assessment	**Assessment**

Data was gathered and analysed through the use of the engineers logbooks, which they were required to keep as part of the assessment process. Logbooks were chosen due to the good representation they can provide of the process followed (McAlpine, Hicks, Huet, & Culley, 2006) and the reliance of under-graduates on hand-drawn representations (Sobek, 2002). Due to study practicalities, it was not possible to use other recording methods to gather further data such as full observation or protocol analysis (Blessing & Chakrabarti, 2009). As a result some tasks, such as those occurring on computers, could not be directly captured. Additionally, the seven studied students were chosen for the apparent completeness of their logbooks, in order to allow detailed coding. Each of these limitations was considered in developing the methodology for the second study.

3.2 Procedure (Study 2)

The second study involved 12 undergraduate trainee engineers at the University of Bath, with an average of 10 months industrial experience. Participants were randomly selected from a total of 40 following a "product design and development" module. Further details of the methodology for this paper have been published elsewhere (Cash, Hicks, & Culley, 2012; Snider, Dekoninck, & Culley, 2012).

The study occurred according to Figure 5 over a period of four hours, designed to mimic a complete design process as described by Hales (1986). Between each stage participants were permitted short, supervised breaks to prevent fatigue, during which they did not discuss the study. Throughout the study, the brief was to develop a remotely operated mount to be placed underneath a balloon for amateur aerial photography. The project brief was therefore constant between designers. Within this research analysis occurred only on the third stage, during which the designers were to

"*Develop an appropriate, feasible, dimensioned, detailed solution*" and were presented with several goals designed to stimulate later stage design activities (such as "*include all component dimensions*". Any conceptual design stage tasks that did occur (as defined in Table 2) were omitted from analysis.

	Stage 1 Information Seeking	Stage 2 Group Brainstorm	Stage 3 Detail Design	Stage 4 Design Review
Duration	50 mins	50 mins	90 mins	50 mins
Teamwork	Individual	Group	Individual	Group

Figure 5: The structure of the second study

In addition to data gathered through logbooks, as occurred in Study 1, data was collected using webcams to view participants, Panopto recording software to capture computer screens (www.panopto.com) and LiveScribe (www.livescribe.com) notebooks and pens to capture real time, detailed logbook data. This comprehensive method ensured that all actions and tasks completed by the designers were captured, unlike within Study 1.

3.3 Further testing

In each study, the designers completed a creative style test similar to that of the Kirton Adaption-Innovation test (M. Kirton, 1976; M. J. Kirton, 1978). This test predominantly differentiates between different creative styles, but has been shown to bear some correlation to creative level (Isaksen & Puccio, 1988). *Adaptors*, by Kirton's definition, are more likely to work within rules and set methods, and excel at precision, reliability and detail. Their creative approach is to "do things better". *Innovators*, on the other hand, are more likely to be undisciplined and adventurous in methods, with a creative approach described as to "do things differently". This description of innovators better matches the traditional interpretation of a creative person (M. Kirton, 1976).
These tests allow validation of the framework and coding scheme against this external, independent measure.

3.4 Coding and analysis process

Coding of logbook data was completed in the same way for each study. Each logbook was coded in three separate passes; the first to allow separation of individual tasks, the second to identify the type of task, and the third to determine if the task displayed evidence of expansion or restraint (therefore if it was *restrained* or *expansive*). Coding in these separate passes allowed higher focus on each individual element of the coding scheme. All passes occurred in one sitting and all coding was completed by a single researcher, to ensure consistency. The exception to this is in the case of testing for intercoder reliability, as described in the following section.

Within the second study, screen capture data was used to provide distinction between a significantly higher number of tasks, capturing further computer-based tasks and providing context to logbook data. Coding of computer-based tasks occurred in the same three passes as the logbook data.

3.4.1 Coding validity and reliability

It is vital when developing a coding scheme that the results it produces are both valid and reliable (Potter & Levine Donnerstein, 1999).

Construct validity of the scheme has been ensured through development from existing literature and repeated application to sample data (which was not included in analysis). Internal validity has been ensured through the rules by which coding occurs, which have been designed to identify entities within the data (which are manifest) but not to influence the coder in their interpretation of the transformations between entities (and hence task types) that exist. This approach is necessary to ensure validity when coding latent pattern data. Furthermore, the results have been compared to the results of an external measure of creative style similar to the Kirton Adaption-Innovation test (M. Kirton, 1976). As the scheme has been designed to measure creative style similar to that of the creative style test, good correlation would suggest validity of the scheme results. This is discussed in Section 4.5.

Reliability analysis of the coding scheme occurred on a sample of 10% of the total tasks from the first study (a suitable quantity for analysis as described by Potter and Levine Donnerstein (1999)). Testing was completed by the original researcher and a single coder who was uninvolved in the development process. The coder was trained and the rules of the scheme re-assessed to ensure reliability according to the recommendation of Krippendorff (1981). This re-assessment was carefully performed as to not decrease scheme validity. The tested sample contained data which was previously unstudied by the testers, and data which was selected for its recorded style, which was particularly difficult to code. To reduce memory effects, the tester waited two months before re-coding this second set of data. Coding achieved a value for Krippendorff's alpha (A. F. Hayes & Krippendorff, 2007) of 0.77, a suitable value for research such as that presented here (Blessing & Chakrabarti, 2009; Klenke, 2008).

4. Results

The following presents the results from each study, together whenever appropriate. Results are initially presented relating to the stages of the design process and focus of tasks within; then the creative approaches appearing within the later design stages and types of task which are typically creative.

4.1 Focus of tasks in different design process stages – Study 1

Within Study 1, designers completed a combined total of 1045 tasks, with an average of 149 per designer. Of these, 32.9% were determined to be non-applicable to the design process, consisting of "to do" lists, phone numbers, or other unrelated administrative occurrences.

Looking at the combined results of all participants in Study 1 throughout the project, there was a switch from a majority of *information* focus tasks to a majority of *application* focus tasks, shown in Table 4. The boundaries between stages of the design process were also consistently fuzzy and often non-chronological, with regular jumps between different types of activities and different levels of detail (Figure 6).

Table 4: Proportion of information and application focused tasks throughout the design process (Study 1)

Design Stage	Task focus (%)	
	Information	**Application**
Analysis and Concept (early stage)	82.9	17.1
Embodiment	38.9	61.1
Detail	36.6	63.4

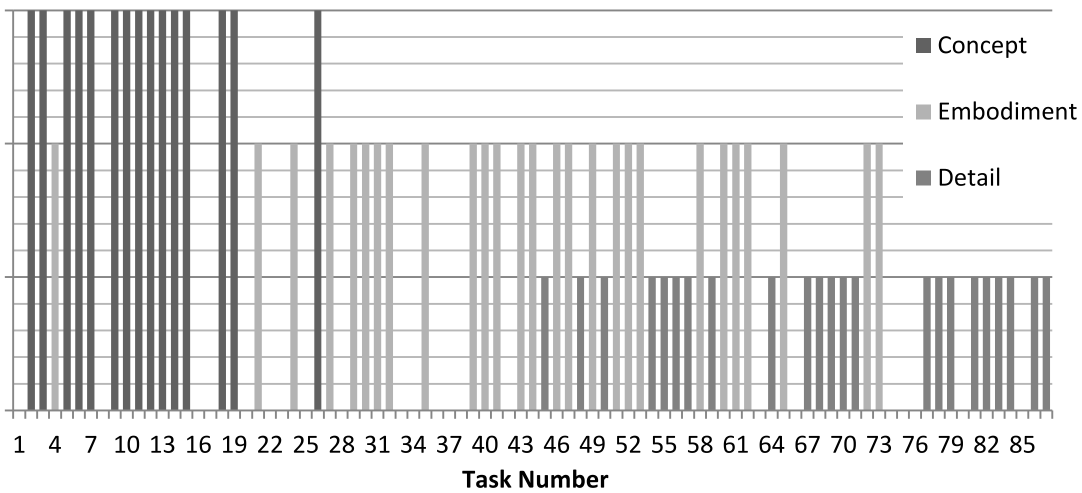

Figure 6: Progression through design stages for designer 1C (Study 1)

4.2 Tasks completed by designers – Study 2

In all, designers completed a total of 119 tasks in the 90 minute period of stage 3 (average 10 per designer). Due to the more restricted nature of the study, designers completed no tasks that needed to be omitted from analysis.

4.3 The appearance of creative design approaches – Studies 1 and 2

Within the later stages, designers completed varying quantities and proportions of *effectuating* (expansive *application* focus) and *astute* tasks (expansive *information* focus). This appeared as a difference in preference for different types of task in which designers were creative, as shown in Table 5. Where referred to directly, each participant has been assigned a number according to the study in which they were involved, and a letter to identify them within each study. For example, participant 1C refers to participant C, who completed study 1.

Creative design approach is determined here by the whether the proportional majority of expansive tasks were *astute* or *effectuating*. As shown, designers all completed a significant proportion of tasks expansively, but showed a wide variation in their predominant creative approach. The means here serve to provide comparability between studies – for example, the proportion of application focus tasks in both studies one and two are high and similar (Table 5; 63.2%, Study 1; 70.9%, Study 2), despite the participants in Study 2 having identical projects, and the in Study 1 different. Furthermore, the variation of expansive proportions around the mean demonstrate the variety in approaches of the designers under the same conditions (Table 5; Study2; average expansive application focus 23.3%; range 0.00% to 50.0%).

Table 5: Proportional later stage creative design approaches (Studies 1 and 2)

Designer	**Information Focus (%)**		**Application Focus (%)**		**Primary approach**
Study 1					
		Expansive Proportion (astute) (%)		Expansive Proportion (effectuating) (%)	
1A	45.2	24.2	54.8	17.5	Astute
1B	48.8	25.0	51.2	47.6	Effectuating
1C	30.0	26.7	70.0	20.0	Astute
1D	15.4	0.00	84.6	18.2	Standard
1E	32.1	40.7	67.9	26.3	Astute
1F	42.9	14.6	57.1	45.3	Effectuating
1G	43.0	23.5	57.0	46.7	Effectuating
Average	36.8	22.1	63.2	31.7	
Study 2					
2A	25.0	0.00	75.0	50.0	Effectuating
2B	5.56	0.00	94.4	23.5	Effectuating
2C	16.7	50.0	83.3	40.0	Astute
2D	44.4	25.0	55.6	40.0	Effectuating
2E	11.1	0.00	88.9	18.8	Effectuating
2F	45.5	40.0	54.5	16.7	Astute
2G	16.7	100	83.3	20.0	Astute
2H	42.9	33.3	57.1	25.0	Astute
2I	33.3	0.00	66.7	16.7	Effectuating
2J	0.00	0.00	100	0.00	Standard
2K	40.0	0.00	60.0	0.00	Standard
2L	33.3	0.00	66.7	0.00	Standard
Average	29.1	20.1	70.9	23.3	

There is a significant tendency in both studies for designers to complete *application* focus tasks in the later stages ($p<0.01$, Study 1; $p = 0.002$, Study 2; Wilcoxon signed rank test). Designer 1D, 2J, 2K and 2L each completed either no tasks expansively or too few for confident analysis of their personal approach. They are thereby classed as following a *standard* approach.

4.4 Creativity of within entity tasks and cross entity tasks – Studies 1 and 2

In both studies, designers completed a majority of *cross entity* tasks in an expansive manner. While designers completed a near even proportion of *within entity* and *cross entity* tasks in Study 1 (Table 6; 47.8% and 52.2% respectively), there was a significant majority of *within entity* tasks in Study 2 (64.2% within entity; p = 0.0076, Wilcoxon signed rank test), as shown in Table 6.

As seen in both studies, there is a significant tendency for designers to complete a higher proportion of *cross entity* tasks expansively (34.2 %, p<0.025, Study 1; 34.3%, p=0.0054, Study 2; Wilcoxon signed rank test), rather than *within entity* tasks.

Table 6: Proportion of within entity and cross entity tasks (Studies 1 and 2)

Study 1					
Designer	**Within Entity Tasks (%)**		**Cross Entity Tasks (%)**		**Majority**
		Expansive Proportion (%)		Expansive Proportion (%)	
1A	39.7	13.8	60.3	25.0	Cross entity
1B	31.7	26.9	68.3	41.1	Cross entity
1C	46.0	8.70	54.0	33.3	Cross entity
1D	74.4	17.2	25.6	10.0	Within entity
1E	63.1	18.9	36.9	51.6	Cross entity
1F	39.3	22.7	60.7	38.2	Cross entity
1G	40.5	31.3	59.5	40.4	Cross entity
Average	47.8	19.9	52.2	34.2	
Study 2					
		Expansive Proportion (%)		Expansive Proportion (%)	
2A	37.5	33.3	62.5	40.0	Cross entity
2B	72.2	15.4	27.8	40.0	Cross entity
2C	66.7	25.0	33.3	75.0	Cross entity
2D	66.7	33.3	33.3	33.3	None
2E	50.0	11.1	50.0	22.2	Cross entity
2F	63.6	14.3	36.4	50.0	Cross entity
2G	66.7	25.0	33.3	50.0	Cross entity
2H	71.4	20.0	28.6	50.0	Cross entity
2I	44.4	0.00	55.6	20.0	Cross entity
2J	90.0	0.00	10.0	0.00	None
2K	60.0	0.00	40.0	0.00	None
2L	83.3	0.00	16.7	0.00	None
Average	64.2	15.1	35.8	34.3	

4.5 Correlation with creativity tests – Studies 1 and 2

For both studies, correlation analysis was performed between expansion within tasks and the creative style test, similar to that of the Kirton Adaption-Innovation test (M. Kirton, 1976). The purpose of this process was to provide an external measure for the assessment of validity of the coding scheme, the presence of a significant correlation indicating a relationship between assessment of creativity by expansion or each designer's creative approach, and designer creative style. Correlations and significance are shown Table 7. The creative style test ranks participants on a normalised scale from *adaptor* (lower scores) to *innovator* (higher scores), where the terms *adaptor* and *innovator* represent participants with different styles of creativity. Those who are stronger *adaptors* are characterised by personal traits such as precision, reliability and efficiency; working within set rules and solving problems in understood ways. Those who are stronger *innovators* are characterised as tangential thinkers, who work in unexpected ways and often challenge rules (M. Kirton, 1976). Correlation then represents the relationship between a higher score on the creative style test (therefore a stronger *innovator*) and the listed variable.

Table 7: Correlation against the creative style test (studies 1 and 2)

Study 1			
First Variable	**Second Variable**	**Correlation**	**Significance (P<…)**
Creative style test	Cross entity type task expansion	0.834	0.00980
	Strength of creative approach	0.804	0.0147
	Later stage expansion	0.790	0.0172
Study 2			
Creative style test	Later stage expansion	0.553	0.0312
	Within entity type task expansion	0.523	0.0406
	Cross entity type task expansion	0.518	0.0422

5. Discussion

By considering both studies in tandem, conclusions can be drawn regarding the behaviour of designers and the approaches that they follow within the design process. Following the same order as Section 4, this section initially discusses the focus of tasks through different stages of the design process, followed by different creative approaches that appear and the types of more typical creative tasks. These are then discussed in the context of the development of designer support.

5.1 Focus of tasks in different stages of the design process

Seen within the individual results of Study 1 (Section 4.1), the framework allows conclusions to be drawn regarding the structure of the design process, as completed in real life by engineers.

The change from predominantly *information* to predominantly *application* focused tasks as the designer moves between early and late stage design highlights the importance of studying creativity in the later stages of the design process as a separate entity. The later stage design process must be considered to have a different focus in terms of the tasks that designers complete within. Other differences between early and later stages have been noted by other researchers, such as the higher quantity of constraints present at later stages (Howard et al., 2011; McGinnis & Ullman, 1990), and the higher impact of later stage design changes on the surrounding systems (C Eckert et al., 2004). This work demonstrates that the actual focus of tasks and predominant creative approach of designers can also vary, underlining the importance of specific research into the later stages of the design process.

Figure 6 also shows frequent switching between different design activities in the real life design process. There is also then perhaps evidence of the suggestion that designers do not progress linearly through stages of increasing detail; frequent jumping and iteration between levels and between components or systems create fuzzy design stage boundaries. Such behaviour has also perhaps been seen by other researchers in work on opportunism (Guindon, 1990; Visser, 1994), (which has been suggested to produces better results by Bender and Blessing (2004)); and the co-evolutionary design process (Dorst & Cross, 2001; Maher, 2000).

5.2 Creative design approaches

As shown by results within Table 5 and Section 4.3, it can be said with some confidence that designers display different creative approaches within the later stages of the design process. While some are more often creative in attempting to identify new knowledge and variables that can be used in the design (*astute* approach), others are more often creative in attempting to find new uses for the knowledge or variables that are already known (*effectuating* approach). This variation exists regardless of whether designers are completing different projects (as in Study 1) or completing the same project (as in Study 2), showing that behaviour is not due to the project, but rather due to the designers' creative style.

Much work in psychology has studied the various effects on creativity of individual factors such as personality (Feist, 1999), skill (Ahmed et al., 2003), and creative style (M. Kirton, 1976), demonstrating that creativity is highly related to the individual and their background. The study of differing creative approaches employed by different designers within the design process, the potential influences leading to their appearance, and the eventual effect of their use; may lead to understanding allowing the development of better designer support. This is further discussed in Section 5.6.

5.3 Focus of tasks

As described in Section 2.4, tasks can also be classified using the coding scheme according to whether the designer maintains focus on a single area when completing a task (termed *within entity*), or whether the designer switches focus from one area to another (termed *cross entity*).

That both studies demonstrated a significant tendency for *cross entity* tasks to be expansive more often (Section 4.4) suggests a pattern for creative behaviour. Designers are more likely to be creative when they are working out how to apply knowledge or variables to a design, or when they are studying the design to develop their knowledge; rather than only developing knowledge or variables, or only refining a design.

Given this tendency, the higher proportion of designers completing *within entity* tasks in Study 2 may be a result of attempting to increase design process efficiency. As a strict and restrictive time limit existed in this study, it was necessary for designers to proceed efficiently in order to complete the brief, limiting the divergence and exploration that could occur.

Although requiring further work to understand fully, there is possibility that the more frequent creativity of cross-entity tasks is related to them more often being ill-defined. Due to the disjunction created when switching focus between information and application (or vice-versa), it may be the case that when completing a cross-entity task, the solution (or path to solution) is less clear than in a within entity task. If correct, such a case would then relate to results from other researchers stating that more creative designers will often structure problems as ill-defined even when a well-defined structure exists (Candy & Edmonds, 1997; Cross, 2004b). When the route to output is not known, it is perhaps necessary for exploration or divergence in order to reach a solution; forming a fundamental part of the creative process (Cross, 2000; Guilford, 1956; Pugh, 1990).

5.4 Correlations with creative tests

Both studies showed significant, medium to high correlation between scores from the creative style test and expansion within tasks as measured by the coding scheme. Additionally, the first study showed correlation between scores from the creative style test and the strength and type of creative approach as measured by the coding scheme. In other words, those who are most often *astute* in their approach are also stronger *adaptors* by the creative test measure; and those who are most often *effectuating* in their approach are also stronger *innovators* by the creative test measure. Validation then exists in that the creative approaches as measured by the coding scheme correlate significantly with the creative style types defined by Kirton (1976). Furthermore, correlation between expansive task proportion and creative style score agrees with existing literature; stating that those who score higher on the creative style test are also often those who display the typical characteristics of a creative person and a creative process (Isaksen & Puccio, 1988; M. Kirton, 1976).

5.5 Cohesion of studies

As demonstrated by similar results from both presented studies (Sections 4.3 and 4.4), conclusions that are drawn stem from designer behaviour, rather than experimental design and methodology.

Differing creative approaches were detected when undertaking a long term study and when analysing a short laboratory study; whether designers were completing different projects or the same; and whether coding using only logbooks or when using more comprehensive recording procedures. Whilst study within industry is required to characterise behaviour of expert designers, the combined sample size of 19 participants is suitable to provide initial conclusions regarding the existence of differing creative approaches.

5.6 Implications for designer support

Within the overall scope of the research, the purpose of the studies presented here is to provide understanding of important considerations for designer support and design process improvement within later stage design.

As described in Section 5.1, the later stages of the design process present a different situation to the designer. It is then important that research in creativity considers the later stages within a different context, and with different requirements from the early stages, until proven otherwise. Whilst a small body of research exists considering designer behaviour within later stage design situations (such as Bender and Blessing (2004) on the subject of opportunism; C. Eckert et al. (2012) on the form of later stage creative changes; and Motte *et al.*(2004) on later stage problem-solving strategy), it is only with significant further work on later stage designer behaviour and creativity that sufficient knowledge will exist to develop evidence-based designer support for later stage design.

To this end, through the evidence of different creative approaches and of typical patterns in creative behaviour as highlighted by this work, it is possible to begin suggesting improved methods of designer support. Multiple options exist through the use of differing creative approaches alone. Stimulating designers according to or against their own creative approach may encourage or discourage the appearance of creative behaviour. Through such control, designers may be able to tailor their process and hence design solution to match the requirements of the company.

There may also be more appropriate levels or styles of creativity for a given design situation, design problem or context; giving opportunities for balancing *non-creative* and *creative* behaviour with their potential benefits to the design outcome and the efficiency of the design process. For example, when encountering a significant design problem a designer may need to be particularly creative in a highly complex situation, hence requiring the enhancement of their own creative behaviour. Conversely, when high time pressures exist it may prove most beneficial to discourage the occurrence of exploratory creative behaviour, instead encouraging the designer to quickly and efficiently produce an output. Depending on the requirements of the situation, knowledge of the style of each designer may allow careful selection of design staff in particular projects, and of careful selection of methods of support.

The more creative nature of *cross entity* tasks (Section 5.3) presents a way in which *non-creative* and *creative* tasks can be stimulated. Consistently encouraging designers to switch between *information* and *application* focus (*cross entity* type tasks) may initiate more creative behaviour. Conversely, consistently encouraging designers to focus on only *information* or *application* focus tasks (*within entity* type tasks) may initiate highly focused behaviour to swiftly complete design activities.

Deeper understanding of the features of later stage design and of the behaviour of designers within it will help develop specific, effective and appropriate methods of support.

6. Conclusions

This paper has presented results from two separate studies into designer behaviour within the engineering design process, with particular focus on the later stages. Through the use of a coding scheme designed to identify different creative approaches, the types of tasks completed by designers have been analysed and patterns within the sequence of their appearance have led to a detailed understanding of individual designer behaviour and creative design approaches. This understanding is required to provide appropriate, effective and efficient methods of designer support.

Both studies were undertaken with undergraduate or trainee engineers, with an average of 5 months of industrial engineering experience for study one and 10 months for study two. The work has shown significant results relating to focus of different stages of the design process, the appearance of creative design approaches and typically more creative tasks (Sections 5.1, 5.2, 5.3); and the framework has been shown to produce repeatable results in varying experiments (Section 5.5) to a good level of reliability (Section 3.4.1) The authors are now undertaking similar activities with more experienced engineers in an industry context.

Analysis has confirmed the appearance of two different creative design approaches within later stage design situations, one of which concerns the *knowledge and variables present for the design to occur*, and the other of which concerns *how that knowledge and those variables can be applied and used within the design.* These creative approaches appear independent of the project completed suggesting that they are a trait of individual designer behaviour, a conclusion supported by correlation with an external creative style test.

The implication of this work, that will need to be further validated with the future work referred to above, is that a thorough knowledge of the creative approaches that designers utilise and the design situation in which they work will allow the enhancement of support of the later stages of the design process. By encouraging or equally discouraging creative approaches the designer may be able to control their process and output for the benefit of the company; increasing process efficiency when under time pressure, or increasing exploration when facing complex problem solving, for example. Also, creative behaviour has been shown to be more common when designers are switching focus between different types of task (Section 5.3), providing initial suggestion for a manner by which creative designer behaviour can be supported.

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