Describing the creative design process by the integration of engineering design and cognitive psychology literature

T. J. Howard, S. J. Culley and *E. Dekoninck*, Innovative Manufacturing Research Centre, Department of Mechanical Engineering, University of Bath, Bath BA2 7AY, United Kingdom

In this paper a 'creative design process' is proposed, based on an integration between a modernised consensus view of both the design process from engineering design and the creative process from cognitive psychology. In addition, a composite definition of a creative design output is also formed, taking elements from the different design types proposed in engineering design and the creative outputs proposed in psychology. This integrated process and the composite definition are further linked, thus providing a descriptive model the different design operations are linked to the types of design output produced.

Keywords: design process, creative process, engineering design, psychology

Creativity is an integral and essential part of the engineering design process. Without creativity in design there is no potential for innovation, which is where creative ideas are actually implemented (Mumford and Gustafson, 1988; Amabile, 1996) and transformed into commercial value (Thompson and Lordan, 1999; Culley, 2002). To emphasise this importance, recent figures were released from the UK treasury concluding that the top innovating companies produce 75% of revenue from products or services that did not exist 5 years ago (Cox, 2005). Within industry, creativity does not necessarily equate to success; however, without it, based on the above observation (Cox, 2005), long-term failure is a near certainty.

Having a full understanding of the processes that lead to creative designs over routine designs is of great interest to both individuals and organisations. There has been work (Chapman, 2006) to establish design processes to enable more creativity; these process models are often termed 'innovation processes'. However, to date there are no descriptive innovation process models able to make clear and consistent distinction between a design path leading to a routine product from a path leading to a creative product. By comparing literature from engineering design with creativity literature from cognitive psychology, this paper highlights some key areas for design researchers to consider. The integration, in some manner, of a creative process with the overall design process

Corresponding author:
T. J. Howard
t.j.howard@bath.ac.uk

www.elsevier.com/locate/destud
0142-694X $ - see front matter *Design Studies* **29** (2008) 160–180
doi:10.1016/j.destud.2008.01.001

may also help engineers to better utilise creativity tools, methods and techniques from both engineering and psychology.

1 Scope of review

In order to conduct this cross disciplinary research, the authors first aimed to identify areas in both engineering design and cognitive psychology literature that are directly comparable, thus making the knowledge transferable. During this initial scoping, it was realised that in psychology it is common to refer to creativity in reference to the four main areas by which it is researched, namely the creative 'process', the creative 'product (output)', the creative 'person' and the creative 'environment' (Rhodes, 1961; Murdock and Puccio, 1993; Basadur et al., 2000). In the domain of engineering design it would appear that leading authors categorise design into broadly similar sections using the terms, the design 'problem', the design 'process', the design 'types (output)', the design 'activity' and the design 'organisation/team/personnel' (Pahl and Beitz, 1984; Ulrich and Eppinger, 1995; Ullman, 1997; Cross, 2000).

The authors previously observed that the engineering design process had many similarities to the creative processes (Howard et al., 2007). In addition, it was seen that the characterised 'design outputs' commonly referred to in engineering design literature, show many similarities with the creative product described in psychology research literature. It was therefore decided that the scope of this paper would attempt to assess and integrate the different perspectives of the two domains with respect to 'process' related research (Section 2) and 'product' or 'output' related research (Section 3). The last two issues considered by the researchers in the psychology area of 'person' and 'environment' are clearly important areas for understanding and supporting creativity, however, they are considered outside the scope of this paper. In Section 4 the findings from the previous sections are brought together to link the design process to the design outputs.

2 The process of creative design

The process by which innovation takes place can be thought of as some form of black box processing large amounts of design related information in order to produce a variety of design outputs, some of which will be 'creative'. Scholars have made attempts to describe and formalise both the engineering design process (Section 2.1) and the creative process (Section 2.2), producing generic models that have been broadly accepted as good representations by both research communities. This paper suggests a descriptive, creative design process that is an integration of the engineering design process and the creative process.

The following sections summarise the key elements of the different engineering design process models and creative process models. Though several forms of process representation have been published from each domain, what can be thought of as the 'linear style' is by far the most dominant in both domains and therefore has been the focus of the work on which this paper has been based. The section concludes with a comparison between the perspectives from each domain (Section 2.3) and a proposed descriptive model of integrating the two perspectives (Section 2.4).

2.1 The engineering design process

The understanding of the design process is important both to manage the design activity and to aid the improvement of products and the overall efficiency of engineering based companies; it is also the foundation on which a lot of design research is based. It is suggested that understanding this process relative to the creative process will give insight into where and when resources should be focused in order to enhance creative performance and also the resulting 'quality' of the product designed. Thus this section introduces a framework (Table 1) which has been generated to define the boundaries of the design process, highlighting the commonalities and differences between the phases it contains. It is based on a detailed analysisof many existing engineering design process models of which 23 are shown in Table 1.

There are a number of notable differences between the models, of particular interest are the divergent–convergent models, which include controlled convergence (Pugh, 1991) and the double diamond (Design Council, 2006) in Table 1. These divergent–convergent models differ from the traditional linear style by assuming some form of integrated evaluation and selection of ideas and concepts. This is potentially a useful outlook on design from a creativity perspective, as separating the generation and evaluation periods is considered good practice for both lateral thinking and brainstorming (Osborn, 1953).

Another slightly atypical form of representation can be described as a 'knowledge space model'. Here it is assumed that a certain quantity of knowledge must be gained for each phase of the process in order to complete a design. These spaces can be filled in random order or sequence, though there are certain dependencies inbuilt within each design project, i.e. one space cannot gain anymore relevant information until knowledge is gained in another space. A prime example of this type of representation is the C–K theory (Hatchuel and Weil, 2003) which describes design as a process of movement between a concept space and a knowledge space. These types of model are probably valid and representative of actual design activities, though it is clear that their high level description makes them less useful to designers. Interestingly, this type of representation did not correspond to the boundaries set by the framework in Table 1.

The column headings used in Table 1 demonstrate the general agreement of design authors on common – often synonymously named – stages. The six headings comprise the four major design phases: 'analysis of task, 'conceptual

Table 1 A comparison of engineering design process models

Models	Establishing a need phase	Analysis of task phase	Conceptual design phase	Embodiment design phase	Detailed design phase	Implementation phase
Booz et al. (1967)	X	New product strategy development	Idea generation / Screening & evaluation	Business analysis	Development / Testing	Commercialisation
Archer (1968)	X	Programming / data collection	Analysis / Synthesis	Development	Communication	X
Svensson (1974)	Need	X	Concepts	Verification / Decisions	X	Manufacture
Wilson (1980)	Societal need	Recognize & formalize / FR's & constraints	Ideate and create	Analyze and/or test	Product, prototype, process	X
Urban and Hauser (1980)	Opportunity identification	Design		Testing		Introduction (launch) / Life cycle management
VDI-2222 (1982)	X	Planning	Conceptual design	Embodiment design	Detail design	X
Hubka and Eder (1982)	X	X	Conceptual design	Lay-out design	Detail design	X
Crawford (1984)	X	Strategic planning	Concept generation	Pre-technical evaluation	Technical development	Commercialisation
Pahl and Beitz (1984)	Task	Clarification of task	Conceptual design	Embodiment design	Detailed design	X
French (1985)	Need	Analysis of problem	Conceptual design	Embodiment of schemes	Detailing	X
Ray (1985)	Recognise problem	Exploration of problem / Define problem	Search for alternative proposals	Predict outcome / Test for feasible alternatives	Judge feasible alternatives / Specify solution	Implement
Cooper (1986)	Ideation	Preliminary investigation	Detailed investigation	Development / Testing & Validation	X	Full production & market launch
Andreasen and Hein (1987)	Recognition of need	Investigation of need	Product principle	Product design	Production preparation	Execution
Pugh (1991)	Market	Specification	Concept design		Detail design	Manufacture / Sell
Hales (1993)	Idea, need, proposal, brief	Task clarification	Conceptual design	Embodiment design	Detail design	X
Baxter (1995)	Assess innovation opportunity	Possible products	Possible concepts	Possible embodiments	Possible details	New product
Ulrich and Eppinger (1995)	X	Strategic planning	Concept development	System-level design	Detail design	Testing & refinement / Production ramp-up
Ullman (1997)	Identify needs / Plan for the design process	Develop engineering specifications	Develop concept	Develop product		X
BS7000 (1997)	Concept	Feasibility	Implementation (or realisation)			Termination
Black (1999)	Brief/concept	Review of 'state of the art'	Synthesis / Inspiration	Experimentation / Analysis / reflect	Synthesis / Decisions to constraints	Output / X
Cross (2000)	X	Exploration	Generation	Evaluation	Communication	X
Design Council (2006)	Discover	Define	Develop		Deliver	X
Industrial Innovation Process 2006	Mission statement	Market research	Ideas phase	Concept phase	Feasibility Phase	Pre production

design', 'embodiment design' and 'detailed design'. Preceding these four phases is the 'Establishing a Need' phase, where the driver for the design is recognised. With just few exceptions (Urban and Hauser, 1980; Baxter, 1995), it is noticeable that nearly all processes assume a market driven process as opposed to a technology driven process. Following the four major phases is the 'implementation phase', which is included by several authors, explaining what happens when the final engineering 'drawings' and instructions are completed. The implementation phase contains only post-design activities and is therefore not the focus of this paper.

It would appear, due to frequent use and reference, that these traditional, linear models (Table 1) of the design process are effective for teaching novice designers and for managing the design process, i.e. for building stage gates upon. However, it is evident that the engineering design process models are poor with regards to representing creative processes. In Table 1 there is one exception in the Fashion and Textile design process proposed by Black (1999), which includes two phases of 'synthesis' and a phase for 'inspiration' both commonly used to describe the creative process (see Table 2). It was also recognised that these linear representations are poor for research purposes particularly for mounting creative tools and processes, partly due to the 'idealistic' way by which they are depicted (Parnes and Clements, 1986).

In order to address this gap, the authors have related this traditional linear view, to a more complex or sophisticated outlook of the design process as proposed by Gero (2004), relating design to function, behaviour and structure (FBS). It is possible to link the FBS framework (Gero, 2004) to three of the four major design phases of the standard engineering design process as illustrated in Figure 1. Here it is suggested that the functions are set within or are analogous to the analysis of task phase, the behaviour of the design is formed in the conceptual design phase and the structure is established during the embodiment phase.

It will be seen that this framework, with its strong links to the usual representations of the design process, can be extremely useful in integrating the engineering design process and the creative process, Section 2.4.

2.2 The creative process

Psychologists can be split into two categories as described by Boden (1990), namely the romantics and non-romantics. The romantics take a more spiritual view of creativity where it is viewed as a mysterious, subconscious process (Barron and Harrington, 1981; Plsek, 1997). This is still quite a common view of the creative process, however, this outlook provides little help to research in engineering design. Conversely, the non-romantic view has a number of very interesting aspects which will be used in this work. Thus the following subsection will take the reader through the different descriptions of several

Table 2 A comparison of creative process models

Models	Analysis phase	Generation phase	Evaluation phase	Communication / implementation phase
Helmholtz (1826)	Saturation	Incubation; Illumination	X	X
Dewey (1910)	A felt difficulty; Definition and location of difficulty	Develop some possible solutions	Implications of solutions through reasoning	Experience collaboration of conjectural solution
Wallas (1926)	Preparation	Incubation; Illumination	Verification	X
Kris (1952)	X	Inspiration	Elaboration	Communication
Polya (1957)	Understanding the problem; Devising a plan	Carrying out the plan	Looking Back	X
Guilford (1957)	X	Divergence	Convergence	X
Buhl (1960)	Recognition; Definition; Preparation; Analysis	Synthesis	Evaluation	Presentation
Osborn (1963)	Fact-finding	Idea-finding	Solution-finding	X
Parnes (1967)	Problem, challenge, opportunity; Fact-finding; Problem-finding	Idea-finding	Solution-finding	Acceptance-finding; Action
Jones (1970)	Divergent Search for data; Understand the problem	Transformation Pattern finding; Flashes of insight	Convergent Judgement	X
Stein (1974)	X Fact-finding	Hypothesis formulation	Hypothesis testing	Communication of results
Parnes (1981)	Mess finding; ; Problem-finding	Idea-finding	Solution-finding	Acceptance-finding
Amabile (1983)	Problem or task presentation; Preparation	Response generation	Response validation	Outcome
Barron and Harrington (1981)	X	Conception; Gestation; Parturition	X	Bring up the baby
Isaksen et al. (1994)	Constructing opportunities; Exploring data; Framing problem	Generating ideas	Developing solutions	Building acceptance; Appraising tasks; Designing process
Couger et al. (1993)	Opportunity, delineation, problem definition; Compiling information	Generating ideas	Evaluating, prioritising ideas	Developing an implementation plan
Shneiderman (2000)	Collect	Create Relate		Donate (communicate)
Basadur et al. (2000)	Problem finding; Fact finding; Problem defn.	Idea finding Diverge – converge at each stage	Evaluate and select	Plan; Acceptance; Action
Kryssanov et al. (2001)	Functional requirements; Structural requirements	Functional solutions; Analogies, metaphors	Reinterpretation	X

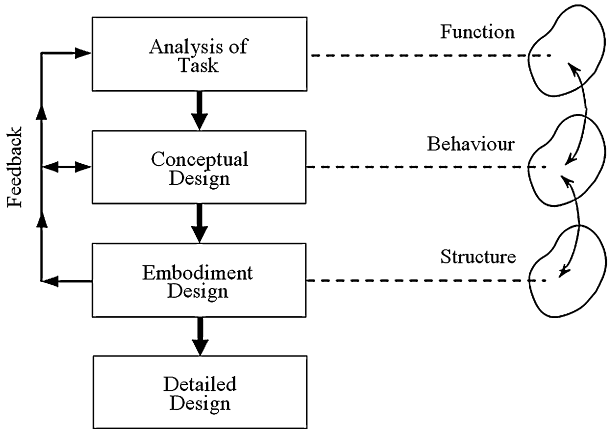

Figure 1 Relationship between FBS (Gero, 2004) and the design process

non-romantic views on creativity. A comparative summary of the process models can be found in Table 2, from which conclusions will be drawn.

Similar to the design process the representation of the creative process takes several forms within the literature. But interestingly, even in the psychology domain, the form is predominantly described as a linear sequence of steps or stages. Earlier descriptions of the creative process, coined by Shneiderman (2000) as ‘inspirationalist’ views, are perhaps the most valuable to engineering design. One of the older process models is the four-stage process offered by Wallas (1926) which although it remains the most well recognised of all creative process models, through his stages of preparation, incubation, illumination and verification, has some critics. This model suggests the sudden emergence of an idea, which is now often deemed somewhat outdated. More recent descriptions, coined by Shneiderman (2000) as ‘structuralist’, attempt to offer an explanation to emergence, describing conscious idea generation as the deliberate connection of matrices of thought (Koestler, 1964). This process is likened to belief by Amabile (1983), where new ideas are generated through the combination of two or more old, existing ideas and is typical of a structuralist view. Both of these views on idea generation stem from Aristotle’s rules of association, though it is noted that neither can distinguish between a process leading to a creative idea and one producing a routine idea.

As with the engineering design process, there are instances of the divergent–convergent style representations of the creative process from psychology literature. It was possible to position some of these processes within Table 2 as they were deemed to be hybrids incorporating divergent–convergent stages into the more common linear process (Guilford, 1957; Jones, 1970; Basadur et al., 2000). Nevertheless, this paper will concentrate on the linear style processes which dominate the representations in Table 2. In constructing this table the 19 process models from the literature were analysed in detail and the various phases were compared and grouped. It was then possible to create four major groupings, which arguably represent the major phases of a creative process as seen by the researchers in the psychology domain. Broadly put, these phases are analysis, generation, evaluation and communication/implementation.

Analysis of the table shows that over time, there has been a general shift from describing the creative process as subconscious cognitive phases (Helmholtz, 1826; Wallas, 1926; Kris, 1952) to activity-based stages (Jones, 1970; Parnes, 1981; Amabile, 1983). It therefore must be noted that due to this shift, phases – particularly in the generation column – are not precisely synonymous. For the purpose of this paper the authors argue that the creative process ends with the evaluation stage, as the communication/implementation phase should be deemed a design activity. Thus the generic creative process model used for this research contains the three stages of analysis, generation and evaluation.

2.3 Comparison between the 'processes' of design and creativity

The previous subsections have created the summary Tables 1 and 2 which contain the major elements identified by authors within the engineering design process (23 in total) and the work on the creative process from the psychology perspective (19 in total). In this section the various views are compared to understand the basis for the integrated model that is presented in Section 2.4. One notable similarity between the processes is the need for information, its analysis and understanding during the initial phases ('analysis of task phase' and 'analysis phase'). This phase is almost identical in both processes and is therefore a central component of the proposed integrated process.

The main differences arise when assessing the conceptual design phase and the embodiment design phase. It would appear that both of these phases contain all three phases of the creative process, namely analysis, generation and evaluation. This emphasises the finer level of granularity of the creative process, where it is seen to repeat continually throughout the first three stages of the design process.

Following the embodiment stage is the detailed design phase when engineering designers produce formal communication documents for manufacture/implementation. In descriptions of the creative process this stage involves the less formal externalising or sharing of the idea and is judged by many to be in addition to the creative process.

In more recent research (Basadur et al., 2000; Kryssanov et al., 2001) psychologists have moved from thinking of the creative process as a cognitive process to a more activity-based one, more analogous to the design process. In doing this, many recent creative process models could, interestingly, be interpreted as extremely generic design process models. This is an interesting convergence of ideas for engineering design authors who have promoted similar ideas for some time (Archer, 1968; Booz et al., 1968). Conversely, the linear engineering design process has remained relatively unchanged, the major developments really only being the inclusion of more feedback loops and the acknowledgment that the design process is more erratic than most representations suggest (Parnes and Clements, 1986; Bucciarelli, 1994).

2.4 Integrated model of the 'process' of creative design

In this subsection the authors will attempt to map the consensus of creative processes (analysis, generation and evaluation) onto a view of the design process. In doing this specific creativity tools can be created and or positioned for their effective use in the design process. For reasons discussed in Section 2.1 the authors have adopted the function, behaviour and structure (FBS) model of design (Gero, 2004).

Figure 2 shows an enhanced version of the FBS model. In grey are the eight different design operations proposed by Gero (2004) (described in Table 3). This splits the behaviour components into expected behaviour (Be) for generative steps and the behaviour derived from the structure (Bs) for evaluative steps. The solid lines represent the different design operations (transformations and comparisons) of the FBS approach which can be found listed in Table 3.

Mapped onto this FBS model are the three creative process elements, shown in black, with the important information transfers shown as dotted lines. Table 3 is also then extended to show how each design operation relates to the stages of the creative process. This gives a view of the creative process from the domain of psychology compared to the view of the design process from the domain of engineering design. The analysis phase is considered central to this model representing the continual interpretation and use of information which is seen as essential to the creative process. It is believed by the authors that the addition of this 'analysis' component is an important addition to the model. The previous FBS framework (Gero, 2004) did not take into account the continual

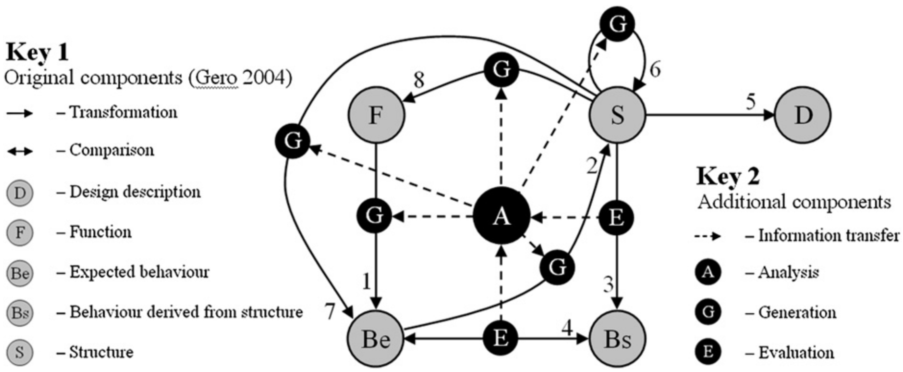

Figure 2 Integrated creative design process model

Table 3 The FBS framework key (Gero, 2004)

Design operation from (Figure 2)	Descriptions of the activities that make up design (Gero, 2004)	Nature of the activities in creative process terms
Formulation (process 1)	Transforms the design requirements, expressed in function (F), into behaviour (Be) that is expected to enable this function.	Generation
Synthesis (process 2)	Transforms the expected behaviour (Be) into a solution structure (S) that is intended to exhibit this desired behaviour.	Generation
Analysis (process 3)	Derives the 'actual' behaviour (Bs) from the synthesized structure (S).	Evaluation
Evaluation (process 4)	Compares the behaviour derived from structure (Bs) with the expected behaviour to prepare the decision if the design solution is to be accepted.	Evaluation
Documentation (process 5)	Produces the design description (D) for constructing or manufacturing the product.	N/A
Reformulation type 1 (process 6)	Addresses changes in the design state space in terms of structure variables or ranges of values for them if the actual behaviour is evaluated to be unsatisfactory.	Generation
Reformulation type 2 (process 7)	Addresses changes in the design state space in terms of behaviour variables or ranges of values for them if the actual behaviour is evaluated to be unsatisfactory.	Generation
Reformulation type 3 (process 8)	Addresses changes in the design state space in terms of function variables or ranges of values for them if the actual behaviour is evaluated to be unsatisfactory.	Generation

growth and manipulation of design information throughout the design process, which was previously encapsulated by the 'analysis of task' phase and the feedback loops.

Figure 2 along with Table 3 shows that transformations 1, 2, 6, 7 and 8 are directly related to the generation stage of the creative process. Operations 3 and 4 are directly linked to the evaluation phase of the creative process. Transformation 5 is deemed as routine design and therefore does not feature in the creative process.

The above model (Figure 2) is a representation linking both the creative process and the engineering design process in a novel and useful manner. In particular it shows the separate ways by which it is possible to assess the generation phases of the creative process in terms of engineering design. This will enable researchers to categorise and focus creative idea generation tools to suit the particular stage or activity that the designer is actually undertaking.

Although considered good representation by the authors, this model, along with all the other processes reviewed in both domains, shows no link to what is referred to as the creative design output (Section 3). It therefore does not make any differentiation between a process leading to a creative design over one leading to a routine design. Thus the creative design output will be discussed and developed in Section 3 with its concluding links to the creative design process being presented in Section 4.

3 The creative design output

A clear definition of, or a metric for assessing creative design outputs consisting of measurable elements, would enable researchers to gauge the effectiveness of any new creativity tools or methods proposed. In this section it will be shown that the classification of 'design outputs' (Section 3.1) in the domain of engineering design – often referred to as design types – closely relates to the research performed by psychologists involving 'creative outputs' (Section 3.2). A comparison between the two different views is produced (Section 3.3) followed by a tabulated model (Table 6) describing how they intersect with respect to the design process. This will help to produce a composite definition of a creative design output in Section 3.4.

3.1 Engineering design outputs

Throughout design research, categorising the different outputs of design has proven to be useful for both analysis and the construction of tools, methods and techniques. The different output types are generally related to a design output's distance from the current paradigm, and are often independent of the discipline or domain. Numerous researchers from the field of engineering design have identified different design outputs, for example the well referenced and simple classification system offered by Pahl and Beitz (1984) detailing three primary classes of design.

Original design: An original solution principle for a system with the same, a similar or a new task.
Adaptive design: Adapting a known solution principle to satisfy a new or changed task.
Variant design: Varying the certain aspects of the system leaving the function and solution principle unchanged.

As with the above scheme, many of the output categories proposed by the various authors clearly differ in the levels of creativity, or at least the novelty, expected to be produced. Table 4 shows how the various authors categorise the different design outputs, where the columns are organised to exhibit the

Table 4 Design output categories

Level of effect	Most original →			Least original
	Behavioural	Functional	Structural	Incremental
Matousek (1963)	New	Adaptive	X	Development
Gasson (1973)	Original	Extensional	Transitional	X
Pahl and Beitz (1984)	Original	Adaptive	Variant	X
Black (1989)	Innovative	Adaptive	Variant	Order
Henderson (1990)	Radical	X	Modular/architectural	Incremental
Culverhouse (1993)	Innovative	Strategic	Variant	Repeat order
Ullman (1997)	Original	Redesign	Configuration	Selection
Gero (2001)	Creative	Innovative	X	Routine

synonymous or closely related design types. The columns are ordered from left to right, decreasing in the levels creativity expected for each design type. Headings were chosen to describe the level at which each design type has the most noticeable effect.

It would appear that by Pahl and Beitz's (1984) definition, the differing design types are clearly related to the design process and thus to the FBS model (Gero, 2004), where 'original' design is assigned to an original 'behaviour' and 'adaptive' design to original 'function'. The authors consider these design type classifications to work over the spectrum of systems' levels, for example on a 'system' level a product may be of type 'variant', however, it may be adaptive and original at 'component' and 'sub-component' levels. The knowledge of this relationship will add to the composite definition described at the end of this Section 3.4.

It was observed that several of the authors also view these design outputs from the initial problem or activity perspective (Ullman, 1997). In which case, it is thought that the designers begin their design work with a notion that the eventual product will be either innovative, adaptive, variant or to order (Table 4) and thus perform the appropriate activity (design type).

While these different design types have the essence of varying levels of creativity, within their definitions they do not explicitly distinguish what is a creative/inventive design from what is a routine design. Ottosson (2001) states that for a product to be new, technically it must have 60% of new or redesigned parts and from a marketing point of view, it needs to be considered new to the market. In engineering design there is one accepted judgment of inventiveness, and it relates to the designs' patentability. In order to become an invention or be granted a patent a design must fulfil the following criteria (The Patent Office, 2007):

- Be new – the invention must never have been made public in any way, anywhere in the world, before the date on which an application for a patent is filed.
- Be capable of industrial application – an invention must be capable of being made or used in some kind of industry. This means that the invention must take the practical form of an apparatus or device, a product such as some new material or substance or an industrial process or method of operation.
- Involve an inventive step – an invention involves an inventive step if, when compared with what is already known, it would not be obvious to someone with a good knowledge and experience of the subject.

Interestingly the first two criteria resemble elements that are used by psychologists to characterise a creative output (i.e. novelty and appropriateness, see Section 3.2). The term unobvious as the third criteria provides a revised definition of a creative output presented previously (Howard et al., 2006), see Table 5.

3.2 Creative output

When defining the creative output it is important to note that an output is considered to be a single idea (Howard et al., 2006). Though this is often termed as the creative product in psychology literature it can cause confusion between the domains, as engineers think of a product as a finished artefact, usually of commercial value.

In the romantic view, the creative output is considered something magical, astonishing (Boden, 1990) or godlike (Goldenberg and Mazursky, 2002), however, most scientific literature describes a creative output as something both original and appropriate. Table 5 displays the various definitions of the non-romantic views of the creative output. It can be seen that the two main elements of originality and appropriateness or their synonyms are present in all definitions. Due to the broad nature of this definition it is common for authors to add some form of third element to their definitions in order to focus on the aspect of creativity their particular research deals with (see Table 5).

It is often easy to gauge how appropriate an idea is through simple testing and evaluation, if it works or fits the specification, it is appropriate. Though researchers from other domains emphasise, there is no right or wrong answer: 'good' rather than 'correct'; 'poor', rather than 'wrong' (Warr, 2007). Other elements such as originality are less robust in definition. Boden (1990) distinguishes between an idea that is original to the beholder (P-Creative) and an idea that is original historically (H-Creative). A good example of this differentiation in reality is in the gyroscope patent. In 1898 an original patent for the gyroscope was finalised, unbeknown that its details could be found in Leonardo da Vinci's notebook dating back to the sixteenth century. It could therefore be argued that the gyroscope patent was P-Creative but not H-Creative. These two types of originality really divide the domains of engineering and cognitive psychology. Engineers are far more concerned with H type originality as it enables intellectual property rights such as a patent (see Section 3.1); psychologists are much more concerned with P type originality, to analyse the creative processes of individuals.

With regards to assessing what is creative in a specific case (i.e. original and appropriate) there are few people who can make this judgment. Amabile (1983) states that there are few objective methods of evaluating the creativity of a product, and for the most part, evaluation is done by applying subjective judgments. This is complemented by Shalley and Gilson (2004) who believe that only a field expert or line manager can judge whether these elements exist in a particular idea, thus determining whether it is creative or not.

Table 5 Creative output definition

Definitions	Originality			Appropriateness							Third Element								
	Novel	Original	New	Appro-priate	Useful	Purpose-ful	Value	Meaning-ful	Tenable	Satis-fying	Un-obvious	Adaptive	Leap	Change	Unexpected	Communi-cated	Transfor-mation	Comparisons	Resource-ful
Jackson and Messick (1965)	X			X													X	X	
Stein (1974)	X				X				X	X			X	X					
MacKinnon (1975)	X									X		X				X			
Rothenberg and Hausman (1976)			X				X									X			
Simon (1979)	X						X												
Amabile (1983)	X			X															
Sternberg (1988)	X				X														
Lumsdaine and Lumsdaine (1995)			X					X											
Gero (1996)			X				X								X				
Marakas and Elam (1997)	X				X														
Thompson and Lordan (1999)			X		X														
Warr and O'Neill (2005)	X			X															
Chakrabarti (2006)	X					X													X
Howard et al. (2006)		X		X							X								
Lopez and Vidal (2006)	X					X					X								

3.3 Comparison between the 'outputs' of design and creativity

The most noticeable difference between the output related definitions from the two domains is in the size and complexity of the output being defined. In engineering design the outputs being defined (the different design types) are complete products, components and solutions, often produced by complete teams of designers. In the case of psychology research the outputs to be defined tend to be 'single ideas' produced by individuals.

In terms of the characteristics that define what is creative from what is routine, psychologists define the creative output with markedly similar criteria to that required for an invention or a patentable design. However, the engineering design community appears to go a step further, breaking these designs further into different design types relating to how creative or original particular aspects of each design are. A common theme emerged from the literature defining the different design types. This tended to distinguish between the levels of creativity exhibited at functional, behavioural and structural levels. This trend is built-in to the composite definition in the following subsection.

3.4 Composite definition of the 'output' of creative design

In order to form a composite definition of the creative design output and thus gain better understanding of the different definitions, it is useful to consider both views alongside the stages of the design process. Table 6 has been generated using the standardised headings of the design process from Section 2.1 along with its relationship to function, behaviour and structure (described by Figure 1). Then taking Pahl and Beitz's (1984) definitions of design types as a standard example it is possible to see how the different design outputs relate to the design process by the relative position of the creative output, within the overall process.

Table 6 indicates that if no creative output is produced the design will be routine at best. The three main design types all contain creative outputs, and can be differentiated between by the FBS relative position in which this creative output occurs. It is obvious from Table 6 that the different design outputs are defined from an engineering/technology perspective, defining an original

Table 6 Design process stage of creative output occurrence for each design type

		Stage of design process			
		Analysis of task (function)	Conceptual design (behaviour)	Embodiment design (structure)	Detailed design
Design outputs	Original		Creative output		
	Adaptive	Creative output			
	Variant			Creative output	
	Routine				

output to be related to behaviour and thus the conceptual design phase. A user orientated classification may see original design being related to function and thus the analysis of task phase (more marketing than engineering) and an architectural orientated classification may see original design being related to its structure.

The following definitions are constructed in reflection of both the definitions of design outputs (Section 3.1) and of creative outputs (Section 3.2).

A creative output: An idea that is both original and appropriate.
A creative design output: A design output containing at least one creative output at the systems' level under study.
A routine design output: A design output containing no creative output at that particular systems' level.

In addition consider the following definitions of the three types of creative design outputs.

Original design output: A design output in which there is a creative output at the behavioural level.
Adaptive design output: A design output in which there is a creative output at the functional level.
Variant design output: A design output in which there is a creative output at the structural level.

The above definitions could be useful for categorising products and product features for research purposes and intellectual property issues. These definitions are now used within the next section to link the creative design process to the creative design output.

4 Link between the creative design process and product

Though fundamental to design research, the process and output of creative design has yet to be linked theoretically or empirically. The following section will propose a simple model consolidating at least half a centuries worth of work from both cognitive psychology and engineering design. The model links the consensus view of the creative design process (Section 2) to the composite definition of the creative design output (Section 3).

It became evident that the generation phase of the creative process has the greatest bearing on the different design outputs (Sections 2 and 3). If any design operation involves a creative generation phase (an original and appropriate idea) then one of the three creative design outputs will be produced. In the case where several creative generation phases occur at one of the systems' levels of the design, then it is a hybrid of the design types. It is important to realise that a routine design has no creative generation phases. Table 7

Table 7 Link between creative design process steps and the creative output

Design operations (Figure 2)	Nature of the activities in creative process terms	Resultant creative design output
Formulation (process 1)	Generation	Original
Synthesis (process 2)	Generation	Variant
Analysis (process 3)	Evaluation	N/A
Evaluation (process 4)	Evaluation	N/A
Documentation (process 5)	N/A	N/A
Reformulation type 1 (process 6)	Generation	Variant
Reformulation type 2 (process 7)	Generation	Original
Reformulation type 3 (process 8)	Generation	Adaptive

identifies five design operations that if performed creatively will lead to the various creative design outputs. The implications of this link between the creative design process and the outputs allow us to position creative design tools respective to the design operation being performed.

With these mechanisms now realised, research must be conducted at lower levels of granularity to understand what detailed mechanisms lead to original and appropriate ideas being produced during the generation phases. In some preliminary theoretical work (Howard et al., 2006) the authors propose that whether an idea is creative or routine is dependent on the information inputs into the process. It is suggested that the 'obviousness' and the 'source' of the information is key to this creative generation process and will be investigated in the following articles.

5 Conclusions

Having reviewed literature from the domains of engineering design and psychology, a creative design process (Figure 2) is proposed as an integration between the engineering design process and the creative process established from cognitive psychology. Whilst acknowledging that design processes observed in practice are more erratic than most representations suggest, it is argued that understanding the linkages in the overall process will help engineers to better utilise creativity tools, methods and techniques. Insight into this process may also reveal where and when resources should be focused in order to enhance creative performance and the quality of the product designed.

A composite definition of a creative design output is also presented, taking elements from the different design types proposed in engineering design and the creative outputs proposed in psychology. A clear definition of a creative design output consisting of measurable elements (originality and appropriateness) will enable researchers to gauge the effectiveness of any new creativity tools and methods proposed. The integrated process and composite definition are linked within Table 7 stating the process routes leading to the different design outputs.

This deeper understanding will enable more effective tools to be created and utilised, helping the engineering designer to produce more original ideas or to reach them more quickly. As it has been shown that information has an important, but not fully understood role, to further the support of creative activities it is clear that studies must be conducted with engineering designers to audit existing information types and sources used as design inputs. In addition, prescriptive studies should be conducted with engineering designers to test the impact of the different types of information on creative inspiration at different stages of the design process.

References

Amabile, T (1983) *The social psychology of creativity* Springer-Verlag, New York

Amabile, T (1996) *Creativity in context* Westview Press, Boulder, Colorado

Andreasen, M M and Hein, L (1987) *Integrated product development* IFS Publications, Bedford

Archer, L B (1968) *The structure of design processes* Royal College of Art, London

Barron, F and Harrington, D M (1981) Creativity, intelligence and personality *Annual Review of Psychology* Vol 32 pp 439–476

Basadur, M, Pringle, P, Speranzini, G and Bacot, M (2000) Collaborative problem solving through creativity in problem definition: expanding the pie *Creativity and Innovation Mangement* Vol 9 No 1 pp 54–76

Baxter, M (1995) *Product design: a practical guide to systematic methods of new product development* Chapman & Hall, New York

Black, I (1989) Product innovation and mechanical CAD: a strategic proposal for engineering manufacture *Computer-aided Engineering Journal* Vol 6 No 5 pp 153

Black, S (1999) *The fashion and textile design process* London College of Fashion, University of the Arts, London

Boden, M (1990) *The creative mind* George Weidenfeld and Nicolson Ltd, Great Britain

Booz, E, Allen, J and Hamilton, C (1968) *Management of new products* Booz, Allen & Hamilton Inc., New York

BS7000 (1997) *Design management systems. Part 2. Guide to managing the design of manufactured products* BSI, London

Bucciarelli, L L (1994) *Designing engineers* MIT Press, Mass

Buhl, H (1960) *Creative engineering design* Iowa State University, Iowa

Chakrabarti, A (2006) Defining and supporting design creativity, in *Ninth International Design Conference Design 06*, Dubrovnik

Chapman, A (2006) *Design process and design management tips* Available from: www.businessballs.com

Cooper, R G (1986) *Winning at new products* Addison-Wesley Publishing Co., Reading, Mass

Couger, J D, Higgins, L F and McIntyre, S C (1993) (Un)Structured creativity in information systems organizations *MIS Quarterly* Vol 17 No 4 pp 375–398

Cox, G (2005) *Cox review of creativity in business: building on the UK's strengths* Available from: http://www.hm-treasury.gov.uk/independent_reviews/cox_review/coxreview_index.cfm

Crawford, C M (1984) Protocol: new tool for product innovation *Journal of Product Innovation Management* Vol 1 No 2 pp 85

Cross, N (2000) *Engineering design methods strategies for product design* Wiley, Chichester

Culley, S J (2002) *The innovation debate* University of Bath, Bath
Culverhouse, P F (1993) Four design routes in electronics engineering product development *International Journal of Design & Manufacturing* Vol 3 No 2 pp 147–158
Design Council (2006) *Double diamond design process* Available from: http://www.designcouncil.org.uk/webdav/harmonise?Page/@id=53&Session/@id=D_4jaHtwk0Hj7ve5elIToe&Document/@id=10149
Dewey, J (1910) *How we think* D. C. Heath & Co., Boston, Mass
French, M (1985) *Conceptual design for engineers* The Design Council, London
Gasson, P (1973) *Theory of design* B T Batsford, London
Gero, J (2001) Mass customisation of creative designs, in *International Conference on Engineering Design*, Glasgow
Gero, J S (1996) Creativity, emergence and evolution in design *Knowledge-Based Systems* Vol 9 No 7 pp 435–448
Gero, J S (2004) The situated function–behaviour–structure framework *Design studies* Vol 25 No 4 pp 373–391
Goldenberg, J and Mazursky, D (2002) *Creativity in product innovation* University Press, Cambridge
Guilford, J P (1957) *A revised structure of intellect studies of aptitudes of high-level personnel* University of Southern California, California
Hales, C (1993) *Managing engineering design* Longman Scientific and Technical, England, Harlow
Hatchuel, A and Weil, B (2003) A new approach of innovative design: an introduction to C–K theory, in *International Conference on Engineering Design, ICED 03*, Stockholm
Helmholtz, H (1826) Vortrage and reden in **H Eysenck** (ed) *Genius* University Press, Cambridge
Henderson, R M (1990) Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms *Administrative Science Quarterly* Vol 35 No 1 pp 9–30
Howard, T J, Culley, S J and Dekoninck, E (2006) Information as an input into the creative process, in *Ninth International Design Conference Design 06*, Dubrovnik
Howard, T J, Culley, S J and Dekoninck, E (2007) Creativity in the engineering design process, in *16th International Conference on Engineering Design, ICED 07*, Paris
Hubka, V and Eder, W E (1982) *Principles of engineering design* Butterworth Scientific, London
Isaksen, S G, Dorval, K B and Treffinger, D J (1994) *Creative approaches to problem solving* Kendall/Hunt Publishing Co., Dubuque, Iowa
Jackson, P W and Messick, S (1965) The person, the product, and the response: conceptual problems in the assessment of creativity *Journal of Personality* Vol 33 No 3 pp 309–329
Jones, J C (1970) *Design methods: seeds of human futures* Wiley-Interscience, New York
Koestler, A (1964) *The act of creation* Macmillan, New York
Kris, E (1952) *Psychoanalytic explorations in art* International Universities Press, New York
Kryssanov, V V, Tamaki, H and Kitamura, S (2001) Understanding design fundamentals: how synthesis and analysis drive creativity, resulting in emergence *Artificial Intelligence in Engineering* Vol 15 No 4 pp 329–342
Lopez, B and Vidal, R (2006) Novelty matrics in engineering design experiments, in *Ninth International Design Conference Design 06*, Dubrovnik

Lumsdaine, E and Lumsdaine, M (1995) *Creative problem solving – thinking skills for a changing world* McGraw-Hill International, New York
MacKinnon, D (1975) *An overview of assessment centres* Centre for Creative Leadership, Greensboro, N.C.
Marakas, G M and Elam, J J (1997) Creativity enhancement in problem solving: through software or process? *Management Science* Vol 43 No 8 pp 1136–1146
Matousek, R (1963) *Engineering design – a systematic approach* Blackie & Son, London
Mumford, M D and Gustafson, S B (1988) Creativity syndrome – integration, application, and innovation *Psychological Bulletin* Vol 103 No 1 pp 27–43
Murdock, M C and Puccio, G J (1993) A contextual organizer for conducting creativity research in *Nurturing and developing creativity: the emergence of a discipline*, Ablex, Norwood, NJ pp 249–280
Osborn, A F (1953) *Applied imagination: principles and procedures of creative thinking* Scribner, New York
Osborn, A F (1963) *Applied imagination: principles and procedures of creative problem-solving* Scribner, New York
Ottosson, S (2001) Dynamic concept development, a key for future profitable innovations and new product variants, in *International Conference on Engineering Design*, Glasgow
Pahl, G and Beitz, W (1984) *Engineering design* The Design Council, London
Parnes, D and Clements, P (1986) A rational design process: How and why to fake it *IEEE Transactions on Software Engineering* Vol 12 No 2 pp 251–257
Parnes, S J (1967) *Creative behavior guidebook* Scribner, New York
Parnes, S J (1981) *The magic of your mind* Bearly Limited, New York
Plsek, P E (1997) *Creativity, innovation, and quality* ASQ Quality Press, Milwaukee, Wisconsin
Polya, G (1957) *How to solve it* Doubleday Anchor Books, New York
Pugh, S (1991) *Total design – integrated methods for successful product engineering* Addison-Wesley Publishers Ltd, Strathclyde
Ray, M (1985) *Elements of design engineering* Prentice-Hall International, UK
Rhodes, M (1961) An analysis of creativity *Phi Delta Kappa* Vol 42 pp 305–310
Rothenberg, A and Hausman, C R (1976) *The creativity question* Duke University Press, Durham, N.C.
Shalley, C E and Gilson, L L (2004) What leaders need to know: a review of social and contextual factors that can foster or hinder creativity *Leadership Quarterly* Vol 15 No 1 pp 33–53
Shneiderman, B (2000) Creating creativity: user interfaces for supporting innovation *ACM Transactions on Computer–Human Interaction* Vol 7 No 1 pp 114–138
Simon, H A (1979) *Models of thought* Yale University Press, New Haven
Stein, M I (1974) *Stimulating creativity* Academic Press, New York
Sternberg, R J (1988) *The nature of creativity: contemporary psychological perspectives* University Press, Cambridge
Svensson, N (1974) *Introduction to engineering design* Pitman, Bath
UK Intellectual Property Office (The Patent Office) (2007) *What is a patent?* Available from: http://www.ipo.gov.uk/whatis/whatis-patent.htm
Thompson, G and Lordan, M (1999) A review of creativity principles applied to engineering design Proceedings of the Institution of Mechanical Engineers, Part E, *Journal of Process Mechanical Engineering* Vol 213 No E1 pp 17–31
Ullman, D (1997) *The mechanical design process* McGraw-Hill International, New York
Ulrich, K T and Eppinger, S D (1995) *Product design and development* McGraw-Hill, New York

Urban, G L and Hauser, J R (1980) *Design and marketing of new products* Prentice-Hall Englewood Cliffs, NJ
VDI-2222 (1982) *Design engineering methodics; setting up and use of design of catalogues* VDI Society
Wallas, G (1926) *The art of thought* Jonathan Cape, London
Warr, A (2007) *Understanding and supporting creativity in design* University of Bath, Bath
Warr, A, and O'Neill, E (2005). Understanding design as a social creative process, in *Proceedings of the Fifth Conference on Creativity & Cognition*, London
Wilson, D R (1980) *An exploratory study of complexity in axiomatic design* Massachusetts Institute of Technology, Mass