Gathering Empirical Evidence Concerning Links Between Computer Aided Design (CAD) and Creativity

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Abstract

Discussion is often reported concerning potential links between computer-aided designing and creativity, but there is a lack of systematic enquiry to gather empirical evidence concerning such links. This paper reports an indication of findings from other research studies carried out in contexts beyond general education that have sought evidence relating CAD and creativity. It describes the establishment of a framework for gathering empirical evidence to support the analysis of links between CAD and creativity, via the observation of creative behaviours, which was developed from published literature largely relating to the area of cognitive psychology. It notes some initial research findings concerning the use of this framework in analysing the use of CAD in postgraduate design projects completed at Loughborough University. These results demonstrate the occurrence of creative behaviours in association with the use of CAD when designing. Finally the significance of these results is discussed within the wider context of design modelling.

Key words

Creativity, computer-aided designing, CAD, empirical evidence, creative behaviours, modelling

Introduction

Computer Aided Design (CAD) is a well-established design modelling tool and has consequently, been introduced in design education worldwide. The CAD in Schools programme was introduced in the UK in 1999, and research has been conducted subsequent to this initiative to explore its implications for designing. For example, a pilot study conducted by Kimbell *et al*, in 2002, suggested that students displayed their enthusiasm for using CAD in designing as it helped them to present designing professionally, visualise the ideas/objects, and work accurately. Research reported by Hodgson and Allsop (2003) found that skill was an essential factor in enabling CAD to be used effectively and with confidence for design development and modelling tasks. Later studies by Hodgson and Fraser (2005) showed that CAD was successfully supporting 'post processes' in design development, was a useful presentational tool and that the virtual reality features in CAD provided designers with an efficient environment to communicate their design thinking with adequate aesthetic quality and design details (Fraser and Hodgson, 2006). Parallel research studies have been reported e.g. in Australia (Chester 2007), (Walther *et al,* 2007), (Robertson and Radcliffe, 2008) and in Austria (Asperl, 2005)

During this period when research agendas relating to the introduction of CAD into schools have been developing, there has also been growing interest in creativity as a key aspect of designing (e.g. Barlex, 2002; Spendlove, 2005). There have been indications that the research agendas concerning CAD and creativity are linked, but there has been a lack of systematic efforts to articulate and clarify what the nature of the links might be (Lawson, 1999). This paper reports four key areas:

- an indication of research findings relating CAD and creativity from beyond general education;
- the establishment of a framework for gathering empirical evidence to support the analysis of links between CAD and creativity via the observation of creative behaviours;
- some initial research findings from postgraduate product design students' projects;
- a discussion of these results within the context of design modelling.

The results of using this analytical framework for the empirical analysis of the links between CAD and creative behaviours have been previously reported by Musta'amal et al at the Engineering and Product Design Education and the Design and Technology Association International Research Conferences in 2008, but the framework itself was not discussed. The analytical framework was first introduced at the Design and Technology Association International Research Conferences in 2006 as a PowerPoint presentation. Summaries of the empirical findings are noted here, but the essential focus of this paper is the analytical framework rather than the results of its use. The essential concerns are to present the links between creative behaviours and creativity which have been reported by cognitive psychologists and the observation of such behaviours when using CAD. The creative behaviours framework is is effectively being used as a bridge between 'CAD' and 'creativity' in order to provide empirical data that can support analysis and discussion. Evidently the same creative behaviours framework could be used in order to explore other design modelling techniques for the purposes of both practice and teaching, learning and (formative assessment). However, these latter areas go beyond the scope of this paper.

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1. Reported links between CAD and creativity

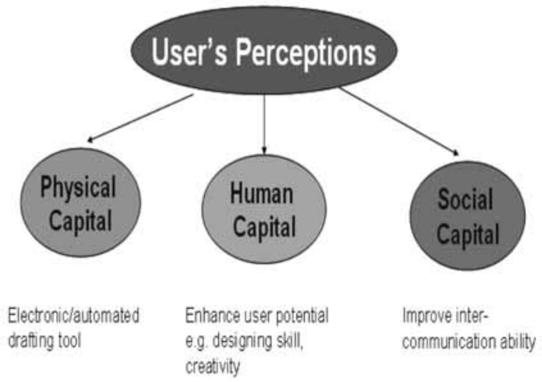

Figure 1: CAD user's perceptions (illustrated by Aede Musta'amal based on Robertson and Allen CAD users' perceptions typology)

An early research study by Robertson and Allen (1991) was conducted to investigate the link between the use of CAD for design, analysis, and communication and engineering performance. Two gas turbine manufacturers which used the same CAD system were involved in this study and seventy-five design engineers participated in the surveys. The study was based on the hypothesis that user perceptions would influence the way CAD was used. Three categories of CAD users' perceptions were used as the research framework as shown in Figure 1. The surveys involved a baseline questionnaire and random occasional daily questionnaires to participants, which focused on documenting CAD usage and communication activities. Interviews with the engineers' manager were undertaken at the end of their project in order to evaluate their performances. The results indicated that CAD could facilitate designers in analysing and communicating design work efficiently. Using CAD for initial designing tasks enabled its later use for design analysis activities and this was clearly supported by the data. It also distinguished that the three-dimensional features in CAD facilitated communication and implied that greater use of CAD communication features might lead to better engineering performance (Robertson, 1993).

There have been growing concerns that using complex CAD software might have detrimental effects on user performance (e.g. ability, creativity, output), and having 'adaptive interfaces' within the system was one possible approach to resolving this issue. Bhavnani *et al,* (1993) studied these concerns in relation to three different levels of CAD users' experience (e.g. novice, regular, and expert). This research was necessary to contribute the development of adaptive interfaces to increase CAD user performance. The research was aimed at establishing the key criteria that could facilitate the recognition of the CAD user's level of experience. Six participants were recruited among students from Carnegie Mellon University and the faculty of Architectural and Civil Engineering departments. They formed three pairs and categories of user:

- low CAD experience (less than a week's experience of using CAD);
- high CAD experience (undertaken at least two projects using 'non CANVAS' CAD software in the past six months);
- high Canvas[1] (frequent CANVAS users).

Participants were given a drawing and required to reproduce it accurately using CANVAS software. Protocol analysis was used as the data collection approach where participants' verbalisations were audio recorded, and completed CAD drawings were saved for analysis. The results indicated that those with high CAD experience showed the ability to transfer their 'knowledge of CAD concepts' and 'procedural knowledge' in different CAD system to establish high quality outcomes' (ibid:327). However, they spent longer than their normal time in completing the task due to the unfamiliar software. The lack of CAD conceptual knowledge prevented the novices from producing an accurate drawing within a sensible time frame. The CANVAS experts produced high quality drawing in the shortest times as a result of their prior experience. These results established a significant link between the prior expertise of the users and their approach to using CAD, the time consumed, and the quality of output produced (ibid:332).

So it has been known for some time that both the perceptions that users have of CAD systems and their expertise can significantly influence their performance. More recent studies have begun to look beyond the designer's performance with the CAD system itself towards its broader designing context (Charlesworth, 2007; Robertson *et al,* 2007).

A recently reported study by Charlesworth (2007) explored the way in which design students used virtual and physical modelling during design development. The study was based on 39 Year 2 product design students at the University of Huddersfield completing a one day project. The students spent the morning developing ideas on paper and the afternoon either modelling these physically or virtually. The study concluded that CAD 'has

[1]CANVAS is a technical illustrations and graphics software package.

little or no value as a stimulus for ideas' (ibid:35). It was claimed that CAD had less significance as a designing tool and suggested that it was only appropriate as a finishing tool to finalise design proposals.

Robertson *et al,* (2007) conducted a more substantial research programme based on industry case studies and an online survey of 200 CAD practitioners from 32 different countries. The findings from the case studies indicated both positive and negative influences on the creative process. The positive effect was found to be related to enhanced visualisation and communication enabled by CAD, and the negative effects were described as premature fixation, circumscribed thinking and bounded ideation. The online survey confirmed that enhanced visualisation and communication, premature fixation and circumscribed thinking were quite widespread in engineering design practice, but that bounded ideation occurs relatively infrequently. It was also found that 'in the early conceptual stages, skills such as sketching, communication and teamwork should take precedence over CAD' (ibid:754), which could be taken as support for Charlesworth's position. Robertson *et al,* (2007) go on to discuss the significance of their findings for design education and the following quotation is from the conclusions of their paper.

> 'Enhanced visualisation and circumscribed thinking cause students to develop a false sense of reality of CAD models, which is divorced from the realities of design in industry. It also influences the students' abilities to creatively develop and effectively communicate their design ideas. These findings point to the need for engineering educators to introduce CAD as part of a more holistic approach, situated within realistic scenarios that foster creativity in the context in which engineered products and systems are made and used. Mastery of CAD is not a substitute for design education. Although CAD has an important role to play, it is but one of many skills needed for a complete design education, and it is one that is in danger of dominating the design education process and the students' conceptions of design. One strategy to achieve a more holistic approach is the wider adoption of Problem Based Learning in the early stages of engineering education programs at the point where design and CAD are introduced; not merely in the capstone experience'. (2007: 759)

For design and technology education research this is clearly a vital research area. CAD is now introduced to students as part of their general education and not in higher education as Robertson *et al,* (2007) seem to suggest. The issues they raise are key matters for design and technology's contribution to general education in schools and colleges, and also of course in order to provide appropriate foundations on which higher education can build. A Keynote Address by Hodgson at the 2005 Design and Technology Association International Research Conference began to explore some of these complexities and in particular the changing situation as a result of the improved skill in using CAD that current students can demonstrate. This improvement is no doubt partly related to improvements in the software and its availability, but Hodgson's concept of the 'malleable' CAD prototype (2006) is indicating how rapidly this area of design education is moving. This paper describes one approach for gathering research evidence that could inform the policy debates that are vital to ensuring that CAD systems play an appropriate role within design education and enhance the creative capabilities of future designers.

2. Developing a framework for gathering empirical evidence to support the analysis of links between CAD and creativity

For an empirical study of CAD and creativity the links could either be observed by the researcher, if there was some external evidence of their existence, or reported by the participant. A framework is needed that can capture such observed and reported creative behaviours. Based on the published literature relating to cognitive psychology, a number of creativity characteristics have been recognised (e.g. (Cropley 1967; Gilchrist 1972; Amabile 1983; De Bono 1994; Balchin 2005). These have been long-listed and grouped into seven categories as shown in Table 1, which is subject to on-going development. The seven categories identified were *novelty, appropriateness, motivation, fluency, flexibility, sensitivity, and insightfulness*. This is not claimed to be an exhaustive list of possible references, but sufficient to generate the majority of the creative behaviours that have been reported. No attempt has been made to select or rank these creative behaviours, they have simply been noted and classified. In order to clarify the nature of the 7 categories a brief discussion of each of them is presented below.

Novelty

Novelty (or originality which is commonly seen as an interchangeable term) can be defined as creating something new and different from that which existed. As novelty is related to creative outcomes in the form of ideas or products, they will be expected to be 'original or, at the very least, uncommon' (Finke *et al,*1992:37). In supporting this, Lubart (1999:339) stated that 'novel work' must have something to do with producing exceptional outcomes, which are 'unexpected or surprising', and completely unique. However, Thomson and Lordan (1999:18) took a less prescriptive view by emphasising that the amalgamation of existing ideas which form unusual outcomes can also be considered as novelty.

Most authors have considered novelty as one of the important elements in defining creativity (e.g. Amabile,1983:33; Cropley, 2001:6). However, many share the view that novelty alone is not enough for an outstanding product to be accepted as creative unless accompanied by appropriateness to the task (Stokes, 1999; Warr and O'Neill, 2005; Weisberg, 1993). This requirement was also indicated by Sternberg and O'Hara's (1999:255) who were of the opinion which that:

> Creativity is often defined as the process of bringing into being something novel and useful.

No	Characteristics	Author(s)
1	Novelty	
	Originality/novelty	Gilchrist, 1972; Finke *et al,* 1992; Lee, 2005; Davis, 1999; Amabile, 1996; Bull and Davis, 1982; El Murad and West, 2004; Thomson and Lordan, 1999; Sosa and Gero, 2005; Bostrom and Nagasundram, 1998; Aguilar-Alonso, 1996; Hocevar and Bachelor, 1987; Shalley *et al,* 2004)
	uncommon	Barron, 1969
2	Appropriateness	
	Appropriate for its purpose	Gilchrist, 1972; Ward *et al,* 1999; Warr and O'Neill, 2005; Brown, 1987
	Practical or sensible	Finke *et al,* 1992
	Operability	Balchin, 2005; Crutchfield, 1973
	Usefulness	Thomson and Lordan, 1999; Sosa and Gero, 2005; Bostrom and Nagasundram, 1998; Aguilar-Alonso, 1996; Shalley *et al;* 2004)
	Be adaptive to reality	Barron, 1969
3	Motivation	
	Motivation	Lee, 2005
	Willingness to take risks; have a go; run-a-risk; risk-taking	Cropley, 1967; Balchin, 2005; Cropley, 2001; Davis, 1999; Lee, 2005; Dacey and Lennon, 1998
	Self-confident	Davis, 1999
	Enthusiastic	Davis, 1999
	Independence	Amabile, 1983; Davis, 1999; Lee, 2005
	Willingness to be provocative	De Bono, 1994
	Preference/attracted for complexity	Amabile, 1983; Crutchfield, 1973; Davis, 1999
	Preference/seeks for challenges	De Bono, 1994; Epstein, 1999
	Complexity of thinking	Gilchrist, 1972
	Task commitment	Lee, 2005
	Perseverance/persistent	Dacey and Lennon; Turner and Dunn, 1970

No	Characteristics	Author(s)
4	Fluency	
	Fluency	Lee, 2005; Hocevar and Bachelor, 1987
	Fluency of ideas	Gilchrist, 1972; Crutchfield, 1973; Guilford, 1973
	Receptive to new ideas	Davis, 1999
5	Flexibility	
	Flexibility	Lee, 2005; Dacey and Lennon, 1998; Hocevar and Bachelor, 1987
	Flexibility of ideas	Finke *et al,* 1992
	Flexibility of thinking	Gilchrist, 1972; Guilford, 1973
	Cognitive flexibility	Crutcfield, 1973
	Elaboration	Finke *et al,* 1992; Lee, 2005
	Redefinition	Crutchfield, 1973
	Possession of wide categories	Cropley, 1967
	Explore the creative possibilities of the ideas	Ward *et al,*1995
	Plays with ideas	Davis, 1999
6	Sensitivity	
	Sensitivity	Amabile, 1983; Lee, 2005
	Sensitivity to problem	Gilchrist, 1972; Turner and Dunn, 1972
	Curiosity	Lee, 2005; Bull and Davis, 1982; Turner and Dunn, 1970
	Sensitive to beauty	Davis, 1999
7	Insightfulness	
	Insightfulness	Finke *et al,* 1992
	Intuitive	Crutchfield, 1973; Davis, 1999
	Redefinition	Crutchfield, 1973

Table 1: Summary table for creativity characteristics reported in literature relating to cognitive psychology

However, Weisberg (1993:4) suggested that evaluation of novelty for creative outcomes should not necessarily be only based on public views, but that the outcome should at least be novel in the eyes of the person who created it. This perception is most useful in the education context where children, students, and novices people cannot be expected to produce something novel in its fullest sense on every occasion. Therefore, the National Advisory Committee on Creative and Cultural Education (NACCE) suggested three levels of 'originality' as a benchmark in evaluating creativity in classroom activities. They were:

'a) Individual
A person's work may be original in relation to their own previous work and output.
b) Relative
It may be original in relation to their peer group.

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> c) Historic
> The work may be original in terms of anyone's previous output in a particular field: that is, it may be uniquely original.'
>
> (NACCE, 1999:30)

Appropriateness

A novel outcome will not be accepted as creative if it does not have appropriateness in terms of use or purpose. Appropriateness can be defined as 'suitable; right and proper' (Hornby, 2000:72), and in the context of creativity research, it refers to a characteristic or behaviour which shifts the status of uncommon and surprising products from being only unique, to being regarded as creative.(Gilchrist, 1972; Brown, 1987; Ward, 1999, Warr & O'Neill, 2005). Some researchers use the term 'usefulness' (Aguilar-Alonso, 1996; Bostrom & Nagasundram, 1998; Thomson, 1999; Shalley, 2004; Sosa & Gero, 2005), Finke *et al,* (1992) used 'practicality' or 'sensibility', whilst, Balchin (2005:39) defined it as 'operability' which not only allowed creative products to be recognised, but also, enable creative people to be identified.

Creative individuals are always involved with identifying problems and problem-solving activities. During problem identification and the exploration of potential solutions, the criteria for solutions are distinguished. These criteria are part of the strategy for assessing and measuring how effective solutions are in solving the problems identified. Creativity would be seen as justified if the outcome was shown to conform to the criteria distinguished (Warr and O'Neill 2005). This agreed with Lubart (1999:339) who defined appropriateness as an act to 'satisfy the problem constraints, useful, or fulfils a need'. And for Gilchrist (1972:14) satisfaction and conformity should either refer to individual (creative person) contentment or to domain justification (e.g. society, association, group).

Motivation

Creative people are motivated by challenging tasks, and excited by the opportunity to use their ability to solve problems in a novel way. They have tendency to go further than their existing potentials. This is also known as 'self-actualisation', a condition which indicates the need of individuals 'to sustain and enhance life in anticipation of their full potential' (Conti and Amabile, 1999:251). Motivation in creativity can be classified into two categories (Collins and Amabile, 1999:299):

a) Intrinsic Motivation
b) Extrinsic Motivation

Intrinsic motivation can be defined as 'the motivation to engage in an activity primarily for its own sake, because the individual perceives the activity as interesting, involving, satisfying, or personally challenging; it is marked by a focus on challenge and the enjoyment by the work itself' (Collins and Amabile, 1999:299). Intrinsic motivation provides creative individuals with the ability to focus on the issues in their work, and consider them in great depth. Creative people will always prepared to face any hitches in their search for a creative outcome within, or maybe even outside their domain.

Extrinsic motivation has been defined by Crutchfield as follows.

> In extrinsic motivation the purpose is not simply the solutions of the problem or the achievement of the creative products per se; these are merely instrumental to further goals of the individual. He seeks to solve problems or to create because of the external rewards that this will bring him. (1973:70).

Extrinsic motivation is based on pursuing external factors such as reward, organisational requirements, competition, social prestige etc. However, some authors have suggested that intrinsic motivation has contributing factor to creativity, while extrinsic motivation might possibly give opposite effect (e.g. Amabile, 1983:195).

Motivation leads to creative individuals having less fear of making mistakes especially when exploring new unexplored areas and willingness to take risks (Amabile,1999; Cropley,1967:43; Balchin, 2005:33; Thurston and Runco,1999:731). This enables them to think and act 'independently' (Amabile,1983:201; Cropley, 2001:11; Balchin, 2005:33), although the consequences might challenge social norms (e.g. ideas, rules, cultures) and hence sometimes lead to disputes. This is supported by De Bono (1994:128) who suggested that to be creative, individuals needs to have attitudes which demonstrate their 'willingness to be provocative and not easily swayed by social norms or beliefs'.

Fluency

Fluency can be defined as ability to 'perform an action smoothly, accurately, and with ease' (Hornby 2000:97). In the context of creative processes, fluency has to do with the ability to facilitate the generation of a number or quantity of ideas (Crutchfield, 1973, Lee, 2005). A creative individual should have the ability to generate more than one idea that is suited to the tasks. In the early research, it was hypothesised that fluency of thinking and ideational fluency would be useful in facilitating a creative individual in producing appropriate ideas in a restricted period of time (Guilford,1959:171; Gilchrist. 1972:5). To encourage the smooth and diverse flow of ideas, their spontaneous capturing and externalising should be facilitated (e.g. brainstorming).

Hence, the concept of fluency should not be limited to the amount of different useful ideas being produced and the smoothness whereby a creative person elaborates from an idea should be considered as an indicator of fluency. Davis (1999) suggested that being open-minded is one 'attitude' that needs to be displayed by creative people and reported that satisfaction with only one idea without letting your mind explore other possibilities is a hindrance to creativity. To generate creative ideas, it is necessary to look at the problems from different angles, and suggest solutions from various perspectives.

Flexibility

The ability to view a problem as a whole and not in a limited perspective is known as flexibility. Thurston and Runco (1999:729) explain the feature of flexibility in creativity as 'a capacity for change' which involves a way of interpreting, and using prevailing information, or approaching the comprehension of tasks, or changes in the plan for undertaking the task. They also elaborate that flexibility might influence an individual's way of thinking, so the task objectives could be interpreted differently. Flexibility of thought will allow individuals to explore possible solutions to defined problems in numerous ways (Gilchrist, 1972:5). This will then lead to the emergence of ideas that may affect not only the intended problems but also other uses or functions. This flexibility of ideas might be represented by a single concept that might be extended to many different conceptual categories in terms of use or functions (Finke *et al,* 1992:39).

Sensitivity

One aspect that is also important in creative people is sensitivity which involves their acute consciousness of what they sense around them which appears to be imperfect, and be responsive to this deficiency. It is the ability 'to see problems' or having 'sensitivity to problems' (Amabile, 1983:201). Creative individuals will not easily be satisfied with the status quo. They have a tendency to question themselves and judge that things are not what they expected. They tend to see inappropriateness in things, and start to think creatively from their dissatisfaction. This leads them to discover the core of hidden problems which are invisible to other people. It is an ability to put together the preliminary problem which requires solution (Gilchrist, 1972:5). The clear understanding of the real problems, allows creative individuals to search with an array of approaches that may lead to possibly unique and apt solutions. They explore the solution to the problem not only for their own interests and satisfaction, but also with societal needs in mind. The outcomes of the creative acts will be instilled with aesthetic aspects to attract public acceptance for their works (Balchin, 2005:39)

Insightfulness

Insightfulness can be defined as 'the number of different knowledge domains the product contacts' (Finke, *et al,* 1992:40). The inter-relation of information between different areas might spark unpredictable answers or solutions to the identified problems. The outcomes of an insight by a creative person may have sensible inferences of use that lie outside of the framework in which it was initially visualised. Sternberg and Davidson (1999) have suggested their own framework for defining insightfulness as a sudden vision of strategy for a long unsolved solution that comes from previous hard work. It involved the emergence of a new uncommon solution from the blend of new with preceding knowledge to unfold ambiguous problems. Insight is not something that appears from nowhere or which comes to the creative mind without any logical explanation. It is reported as occurring as a result of intense thought or action on the task, and when the solution did not come into sight instantly, but through the process of time.

An insight can occur at any moment within creative people, whilst intuition plays a great role in creating an imaginary boundary for the divergent thinking process. It can also be seen as the phenomena of cognitive unconsciousness in creativity which prevents burden to the conscious mind during the processes of integrating various pieces of information (Weisberg,1993:42). Policastro (1999:89) defined intuition as information which influences individual consciousness of thought that leads to a potentially sensible decision. The intuition will lead to a possible outcome by combining new information and prior knowledge in a selective and reasonable manner. Based on this definition, intuition is seen to precede insight. It is the reconstruction process of the implicit form of knowledge to an integrated and explicit one.

The analytical framework

The analytical framework resulting from this literature search has been named as the Creative Behaviours Model and is summarised in Figure 2. The seven categories are shown and also three descriptors which help to explain the meaning of the seven terms chosen.

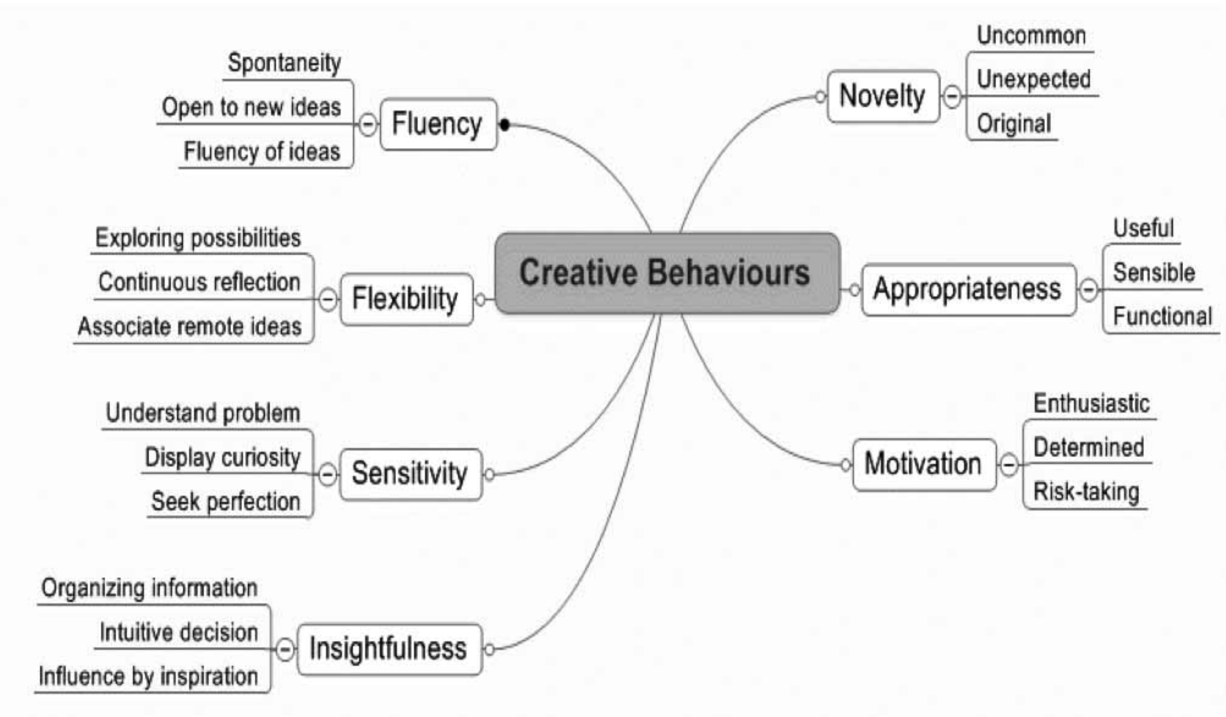

Figure 2: Creative behaviours model and its descriptors

3. Some initial research findings from the use of this framework in analysing case studies of designing by industrial design masters students

An initial study was conducted with a group of postgraduate students in the Design and Technology Department, Loughborough University. The students were given a brief presentation about the research and how they could be involved as participants. Four students volunteered, but one only completed the preliminary interview. The study was based on their masters or research design projects. The data collection process only involved design activities that used CAD. The aim was to establish the link between CAD and creative behaviours in designing.

Throughout the study, a series of qualitative approaches consisting of interviews, protocol analysis, observations, and design diaries were conducted for data gathering. Interviews were carried out before the design project commenced to give an initial overview of participants' perceptions about the roles of CAD in their projects. Interviews were undertaken because of their potential to generate 'unlimited' and detailed information of individual understanding in order to illustrate findings and support hypotheses (Goulding, 2002). In order to give consistent types of questions and stimulate participants' responses, a set of pre-set questions was established, and used... The interviews were recorded and later transcribed for analysis.

Observation, and protocol analysis approach was also undertaken to gather firsthand data and provide indications about whether CAD influenced creative behaviours in designing. Protocol analyses were undertaken as in other research studies where there has been a significant increase in the use of protocol analysis in studying design activities in recent years (Cross *et al,* 1996).

Pre-arranged design sessions were audio and video recorded. Video data enabled the capture of important events that were difficult to observe in real time and facilitated the microanalysis of potentially significant events (Paterson et al, 2003). Analysed data were presented in form of video clips in PowerPoint, and shown to the designers in order to confirm interpretations.

Designers' modes of work tend to be more flexible in terms of time, and/or workplace and for these reasons, a formatted diary was provided that would allow designers to record significant information related to their design work. This is supported by Pedgley (1999:108) who stated that:

Creative behaviours categories	Creative behaviours descriptors	Protocol Analysis	Video Observation	Direct Observation	Design diaries	Total	% Percentage
Novelty	uncommon					0	0
	unexpected					0	0
	original					0	0
Appropriateness	useful				4	4	2
	sensible	23	2	2		27	11
	functional	1			7	8	3
Motivation	enthusiastic	1	3	3	3	9	4
	determined	3	7	6	6	22	9
	risk-taking	15	4	3	2	24	10
Fluency	spontaneity					0	0
	open to new ideas	2	3	1	2	8	3
	fluency of ideas	5			3	8	3
Flexibility	exploring possibilities	14	5	3	1	23	9
	continuous reflection	23	10	3		36	15
	associate remote ideas			1	1	2	1
Sensitivity	understand problem	3			3	6	2
	display curiosity	4	1	1	3	9	4
	seek perfection	18	13	5	5	41	17
Insightfulness	organizing information	10		1	2	13	5
	intuitive decision		2			2	1
	influence by inspiration				4	4	2
	Total	122	50	29	46	247	100%

Table 2: Tabulated frequency of creative behaviours occurrences (Reproduced from Musta'amal et al, 2008a:719)

> A diary appeared… to be a suitable method for recording longitudinal design activity from the designer's perspective.

Essentially, the design diary was developed to record a set of information by participants each time when CAD was used in design activities. The design diary was designed to record 'when, where, why, and how' they used CAD for designing.

The seven categories of creative behaviours derived from the literature provided a framework for observing and recording their occurrences when CAD was used in designing. The results obtained from the analysis are, presented in Table 2. In total, 247 creative behaviours were detected during the analysis. From twenty one creative behaviours descriptors, seventeen were recorded as occurring at least once. However, out of 7 creative behaviour categories, only 6 were able to be observed using the research framework. Data concerning novelty was not recorded, which could be a result of not including an analysis of the final outcomes within the data gathering, but might also suggest that the research instrument needs further refinement (Musta'amal *et al,* 2008a, 2008b). Nevertheless, the results showed consistent occurrences by a number of creative behaviours during the CAD sessions, and hence significant links between creative behaviours and the use of CAD in design activity.

From the analysis, two types of CAD user categorised on the basis of their prior perceptions of the roles of CAD in designing could be distinguished. In the preliminary interviews, participants were asked the way they were going to involve CAD in their design projects. Some of the responses from the transcriptions are shown in Table 3. It was clear that the four participants were grouped into two types of user categories who perceived CAD as a *recording tool (recorder) and designing tool (designer).*

In this analysis, the data from design diaries were excluded, which explains why the total numbers of observed creative behaviours recorded were different as shown in Tables 3 and 4. The results in Table 4 show that higher frequencies of creative behaviours were distinguished from P03 and P04 compared to P02 ie 63 creative behaviour occurrences were observed for P02, 99 for P03 and 100 for P04. These figures indicate that all users demonstrated creative behaviours when using CAD,

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ID Code	Where CAD fits [WFT]	CAD user types
P01	'... ..I mostly use CAD for just to get renders... .. just to get photo realistic images... . the main purpose.'	Recording tool
P02	'After we've got the final..'	Recording tool
P03	'I think I will introduce computer [CAD} even like in the beginning of my designing [start from the beginning]... ..'	Designing tool
P04	'And, basically, I'm using CAD from the start to finish.'	Designing tool

Table 3: Types of CAD user identified

even PO2 who was a 'recorder'. However, the 'designers' who anticipated using CAD throughout designing displayed more. These results support prior research by Robertson and Allen (1991;1993), but also demonstrate a wider contribution of CAD to creative behaviours for all users.

4. Considering these results within the wider framework of design modelling: their limitations

The empirical data reported here relates to the observation of creative behaviours when designing. They relate to a small sample of postgraduate design students who were using CAD packages suitable for product design. There is no prospect of generalising results from a small number of case studies, and it was not the intention of this paper to make such a generalised contribution concerning the empirical outcomes. However, the potential for using the creative behaviours model for analysing behaviours observed when design modelling has potentially wider significance. In an educational context it could have more general implications in relation to the design of teaching programmes, formative assessment, or simply the observation and interpretation of classroom behaviour.

However, making links between creative behaviours and creativity is inevitably problematic, not least because creativity is a complex topic and one that remains a

Creative behaviour	Descriptors	P02	P03	P04
Novelty	uncommon	0	0	0
	unexpected	0	0	0
	original	0	0	0
Appropriateness	useful	0	0	0
	sensible	10	11	16
	functional	0	1	0
Motivation	enthusiastic	2	2	1
	determined	7	9	8
	risk-taking	7	12	11
Fluency	spontaneity	0	0	0
	open to new ideas	0	4	2
	fluency of ideas	3	0	2
Flexibility	exploring possibilities	6	12	7
	continuous reflection	15	13	18
	associate remote ideas	1	3	1
Sensitivity	understand problem	0	0	3
	display curiosity	0	4	2
	seek perfection	8	23	23
Insightfulness	organizing information	4	3	5
	intuitive decision	0	2	1
	influence by inspiration	0	0	0
	Total	**63**	**99**	**100**

Table 4: Creative behaviour occurrences between participants (Recorder vs Designer)

Gathering Empirical Evidence Concerning Links Between Computer Aided Design (CAD) and Creativity

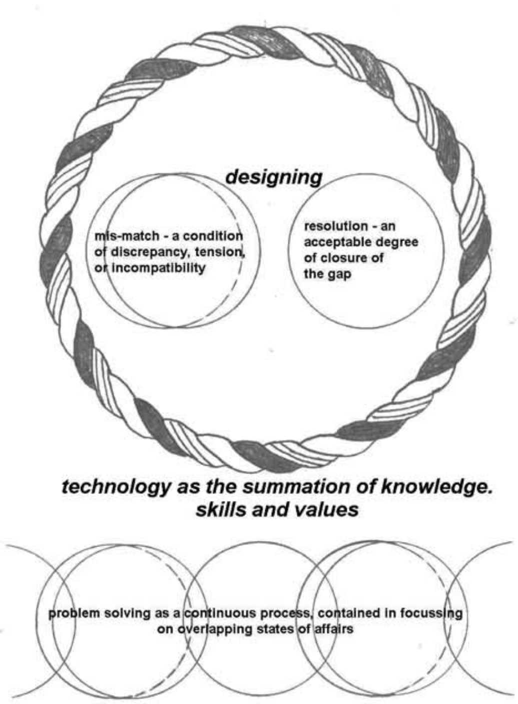

Figure 3: Technology as the summation of knowledge, skills and values (Norman, 2000:129)

'slippery concept' (Spendlove, 2005:9). It has an 'elusive definition' (NACCCE, 1999) with a wide range of possibilities. Creativity rather than having one universal definition, embodies a variety definitions (Dewulf and Baillie, 1999:5) and has been defined in many ways by researchers, based on their perspectives and interests. One way of categorising definitions of creativity is by grouping them as relating to the product, the person,

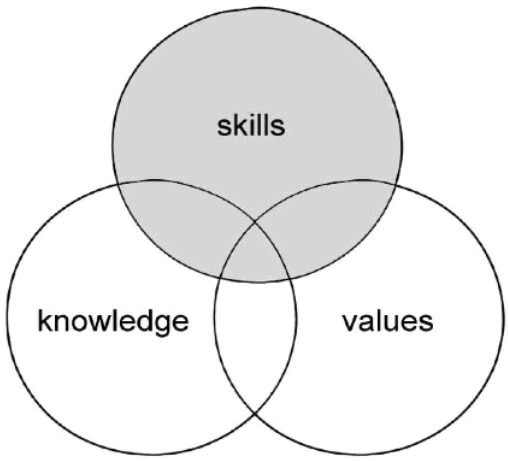

Figure 4: A cross-section of a boundary of designing represented by knowledge, skills and values

the process (Amabile,1983:17; Balchin, 2005: 32) or press (the environment). These have become known as the '4Ps' (Richards, 1999). This interpretation of creativity as a spectrum of meanings is one of the reasons for the difficulties in researching this area and a second is the requirement for any credible model of the act of designing to engage simultaneously with knowledge, skills and values. This has been well understood since at least the Assessment of Performance Unit Report (Hicks *et al,* 1982), which explored the nature of design and technology.

The constraints on the performance of an individual or group of designers need to be seen in relation to the knowledge, skills and values they possess or can access as shown in Fig.3 and Fig 4. The implications of this model concerning knowledge and values were discussed in the 2006 John Eggleston Memorial Lecture (Norman, 2006), and when reflecting on the skill of CAD as a tool supporting design decision-making, this must be considered alongside knowledge and values. Thus is it is inappropriate to attempt to make detailed comparisons between the outcomes for the postgraduate students reported here and the prior research reviewed concerning professional designers. The use of CAD is but one designing skill amongst many. However the prior research has demonstrated that one strong influence on the effectiveness of CAD's use in designing is the users' perceptions of its potential, which was supported by the data reported here.

By being inclusive rather than selective, the analytical framework developed accepts the spectrum of interpretations of creativity and by adopting a case study approach there is the potential to consider the research evidence obtained in relation to particular sets of knowledge, skills and values.

Conclusions

It can be stated that it is possible to observe and record instances of the behaviours that cognitive psychologists have associated with creativity when CAD is used for designing. This clearly distances these research results from naïve interpretations ie that CAD is not a creative designing tool. Its use can certainly be associated with creativity, and the activities its supports associated with creative behaviours. The study has also identified two types of CAD users known as *recorders* and *designers* as distinguished by their perception of CAD's potential. The empirical evidence reported supports earlier early studies in demonstrating that a *designer* who anticipated using CAD throughout designing would display more creative behaviours than other users. However, creative behaviours were observed in the CAD use of all the participants reported here. The potential for using the creative behaviours model in relation to other types of design modelling and teaching, learning and (formative) assessment strategies is evident.

References

Aguilar-Alonso, A. (1996). "Personality and Creativity." *Person Individual Differences* 21(6), 959-969

Amabile, T. M. (1983). *The Social Psychology of Creativity.* Springer-Verlag: New York

Amabile, T. M. (1996). *Creativity in Context.* Westview Press: Boulder, Colorado

Asperl, A. (2005). "How to Teach CAD." *Computer-Aided Design Applications.* 2(1-4), 459-468

Balchin, T. (2005). "A Creativity Feedback package for teachers and students of design and technology (in the UK)." *Design and Technology Education: An International Journal* 10(2), 31-43

Barron, F. (1969). *Creative person and creative process.* Holt, Rinehart & Winston: New York, London

Barlex, D (2002). *Creativity in Crisis?: Design & Technology at KS3 and KS4.* Report from Nuffield-DATA Seminar on 10th September 2002.

Bhavnani, S K, Garret, J S and Shaw, D F (1993). Leading Indicators of CAD Experience. *CAAD Future '93*, Elsevier Science Publisher BV

Bostrom, R. P. and M. Nagasundram (1998). Research in Creativity and GSS. *Thirty-First Hawaii International Conference on System Sciences*, Hawaii

Brown, R. T. (1987). Creativity: What are we to measure?. In *Handbook of Creativity*. J A Glover, R R Ronning and C R Reynolds (eds). Plenum Press: New York, London, 3-32

Bull, K. S. and G. A. Davis (1982). "Inventory for Appraising Adult Creativity." *Contemporary Educational Psychology*, 7, 1-8

Charlesworth, C. (2007). "Student Use of Virtual and Physical Modeling in Design Development-An Experiment in 3D Design Education." *The Design Journal*, 10(1), 35-45

Chester, I. (2007). "3D-CAD: Modern Technology – Outdated Pedagogy?" *Design and Technology Education: An International Journal* 12(1), 3

Collin, M A and Amabile T M (1999). Motivation and Creativity. In *Handbook of Creativity*. R J Sternberg (ed). Cambridge University Press: Cambridge

Conti, R and Amabile, T M (1999). Motivation/Drive. In *Encyclopedia of Creativity*. M. A. Runco (ed). Academic Press: San Diego, London, Boston, New York, Sydney, Tokyo, Toronto Diego 2

Cropley, A. J. (1967). *Creativity*. Longmans, Green & Co. Ltd: London

Cropley, A. J. (2001). *Creativity in education and learning.* Kogan Page: London

Cross, N, Christiaans, H and Dorst, K(1996). *Introduction; The Delft Protocols Workshop in Analysing Design Activity.* John Wiley and Sons: Chichester. New York, Brisbane, Toronto, Singapore

Crosbie, T (2006). Using Activity Diaries: Some Methodological Lessons. *Research Practice*. 2 (1), 1-13

Crutchfield, R. S. (1973). The Creative Process in *Creativity: Theory and Research*. N Bloomberg. College and Univerity Press: New Haven, Connecticut

Dacey, J. S. and Lennon, K H (1998). *Understanding Creativity: The Interplay of Biological, Psychological, and Social Factors*. Jossey Bass: San Francisco, California

Davis, G. A. (1999). Barriers to Creativity and Creative Attitudes. *Encyclopedia of Creativity*. M. A. Runco (ed). Academic Press: San Diego, London, Boston, New York, Sydney, Tokyo, Toronto Diego 1

De Bono, E. (1994). *Parallel Thinking*. Penguin Group: London

Dewulf, S and Baillie, C (1999). *How to foster Creativity*. Department of Education and Employment: U K

El-Murad, J. and D. C. West (2004). "The Definition and Measurement of Creativity: What Do We Know?" *Journal of Advertising Research*, 44(2), 188-201.

Epstein, R. (1999). Generativity Theory. In *Encyclopedia of Creativity*. M. A. Runco, and Pritzker, S R (eds). Academic Press: San Diego, London, Boston, New York, Sydney, Tokyo, Toronto 1, 759-766

Finke, R. A., Ward, T B and Smith, S M (1992). *Creative Cognition: Theory, Research, and Applications*. MIT Press: Cambridge, Massachusetts, London, England

Fraser A and Hodgson A.R (2006) 'Application of Computer Aided Design and Manufacture in School-based Design'. In E W L Norman, D Spendlove and G Owen-Jackson (eds), *Designing the Future, DATA International Research Conference*, The Design & Technology Association, Wellesbourne, UK, 59-68

Gilchrist, M. (1972). *The Psychology of Creativity.* Melbourne Press: Hong Kong

Goulding, C. (2002). *Grounded Theory: A Practical Guide for Management, Business and Market Researchers*. SAGE Publications: London, Thousand Oaks, New Delhi

Guilford, J. P. (1973). Traits of Creativity. In *Creativity*. P. E. Vernon (ed). Penguin Education: Great Britain

Hicks G *et al,* (1982) *Understanding Design and Technology*, Assessment of Performance Unit: London

Hocevar, D. and P. Bachelor (1987). A Taxonomy and Critique of Measurements Used in the study of Creativity. *Handbook of Creativity*. J A Glover, R R Ronning and C R Reynolds (eds). Plenum Press: New York, London, 53-75

Hodgson A R (2006) 'Digital Design – the Potential of Computer Aided Designing in Design Learning Environments', *Design and Technology Education: An International Journal* 11 (1), 10-17

Hodgson A R and Allsop C (2003) 'Beyond Pro DESKTOP Computer Aided Design (CAD): The Transfer of CAD-based Design Modeling Skills From Schools to Higher Education'. In E W L Norman and D Spendlove (eds). *Design Matters, DATA International Research Conference.* The Design & Technology Association, Wellesbourne, UK, 45-49

Hodgson, A R and Fraser, A (2005) 'The Impact of Computer Aided Design and Manufacture (CAD/CAM) on School-based Design Work'. In E W L Norman, D Spendlove and P Grover, (eds). *Inspire and Educate, DATA International Research Conference.* The Design & Technology Association, Wellesbourne, UK, 95-106
Hornby, A. S. (2000). Oxford Fajar: Advanced Learner's English – Malay Dictionary. Shah Alam, Oxford University Press – Penerbit Fajar Bakti: Kuala Lumpur

Kimbell, R, Lawler, T, Stables, K and Balchin, T (2002). Pro/DESKTOP in Schools: A pilot research study. *Journal of Design and Technology Education*. 7(1), 29-34

Lee, K.-H. (2005). "The Relationship Between Creative Thinking Ability abd Creative Personality of Preschoolers." *International Education Journal* 6(2), 194-199

Lawson B (1999) ''Fake' and 'Real' Creativity using Computer Aided Design: Some Lessons from Herman Hertzberger' ACM: *Creativity and Cognition*, Loughborough, UK

Lubart, T I (1999). Creativity Across Cultures. In *Handbook of Creativity*. R J Sternberg (ed).Cambridge University Press: Cambridge, New York, Melbourne, Madrid, Cape Town.

Musta'amal A H, Norman, E W L and Hodgson, A R (2007) PowerPoint *Education & International Research Conference 2008*, Loughborough, Leicestershire, The Design and Technology Association

Musta'amal, A. H., Hodgson, A R, Norman, E N (2008a). CAD and Creativity: Reality or Myth?. . *New Perspective in Design Education, Engineering and Product Design Education Conference*, Institution of Engineering Designer, The Design Society

Musta'amal, A. H., Norman, E N and Hodgson, A R (2008b). CAD as a 'Recording' or 'Designing Tool: Evidence from User Behaviours. *Education & International Research Conference 2008*, Loughborough, Leicestersgire, The Design and Technology Association

Norman E (2000) 'The Teaching and Learning of Technology for Design'. In Kimbell R (ed) *Design and Technology International Millennium Conference 2000*, The Design and Technology Association, Wellesbourne, UK, 128-134

Norman E W L "The Professor John Eggleston Memorial Lecture 2006: values, human judgement and sustainability in design and technology education", *Design and Technology Education: an International Journal*, 11(3), 11-34

Paterson, B. L, Bottorf, J L and Hewat, R (2003). "Blending Observational Methods: Possibilities, Strategies, and Challenges." International Journal of Qualitative Methods 2(1)

Pedgley, O (2007). Capturing and Analysing Own Design Activity. *Design Studies*. 28(5), 463-483

Policastro, E (1999). Intution. In *Encyclopedia of Creativity*. M A Runco and S R Pritzker (eds). Academic Press: San Diego, London, Boston, New York, Sydney, Tokyo, Toronto Diego. 2

Richards, R (1999). Four P's of Creativity. In *Encyclopedia of Creativity*. M A Runco and S R Pritzker (eds). Academic Press: San Diego, London, Boston, New York, Sydney, Tokyo, Toronto Diego. 1

Robertson, B. F. and D. F. Radcliffe (2008). "Impact of CAD tools on creative problem solving in engineering design." *Computer-Aided Design* In Press, Corrected Proof

Robertson, B F, Walther, J and Radcliffe, D F (2007). "Creativity and the Use of CAD Tools: Lessons for Engineering Design Education from Industry." *Journal of Mechanical Design* 129, 753-759

Robertson, D. and T. J. Allen (1991). *CAD System Use and Engineering Performance* in Mechanical Design, Sloan School of Management, Massachusetts Institute of Technology

Robertson, D and Allen, T.J (1993). "CAD System Use and Engineering Performance." *Transactions on Engineering Management* 40(3)

Shalley, C, Zhou, E J et al. (2004). "The Effects of Personal and Contextual Characteristics on Creativity: Where Should We Go from Here?" *Journal of Management* 30(6), 933-958

Sosa, R., Gero, J S (2005). "A computational study of creativity in design: The role of society." AI EDAM: *Artificial Intelligence for Engineering Design, Analysis, and manufacturing* 19(4), 229-244

Spendlove, D (2005). Creativity in Education: A Review. *Design and Technology Education: An International Journal*. 10 (2), 9-18

Sternberg and Davidson (1999).Insight. In *Encyclopedia of Creativity*. M. A. Runco and S. R. Pritzker (eds). Academic Press: San Diego, London, Boston, New York, Sydney, Tokyo, Toronto Diego. 2, 57-69

Sternberg, R and O'Hara, L (1999). Creativity and Intelligence. In *Handbook of Creativity*. R J Sternberg (ed). Cambridge University Press: Cambridge, New York, Melbourne, Madrid, Cape Town

Stokes, P. D. (1999). Novelty. In *Encyclopedia of Creativity.* M A Runco and S R Pritzker (eds). Academic Press: San Diego, London, Boston, New York, Sydney, Tokyo, Toronto Diego. 2, 297-304

Thomson, G, and Lordan, M (1999). A Review of Creativity Principles Applied to Engineering Design. *Proceedings of the Institution of Mechanical Engineers.* 213 (10), 17-31

Turner, B T and Dunn, S C (1970). The Range of Procedures and Strategies: Part 2. *Creativity and Innovation in Engineering Conference* Birmingham

Walther, J, Robertson, B F and Radcliffe, D F (2007). Avoiding the potential negative influence of CAD tools on the formation of students' creativity. *AaeE Conference 2007*, Melbourne, Australia

Ward, T. B., Finke, R A, Smith, S M (1995). *Creativity and the Mind: Discovering the Genius Within*. Plenum Press: New York, London

Ward, T. B., Finke, R A, Smith, S M (1999). *Creativity and the Mind: Discovering the Genius Within*. Plenum Press: New York, London

Warr, A. and E. O'Neill (2005). Understanding Design as a Social Creative Process. *5th Conference on Creativity & Cognition* London, ACM

Weisberg, R. W. (1993). *Creativity Beyond The Myth of Genius*. W H Freeman Company: New York

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