Creativity in research and development environments: A practical review

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ABSTRACT

Creativity is of paramount importance to the innovation process. Therefore the findings of creativity research should be thoroughly considered in organisations where innovation processes are required. This review summarises the literature in the field of work place creativity, with special attention given to R&D environments. Current theoretical models of creativity are discussed and a literature review of the influence of (i) motivation, (ii) interaction within work groups and between group leaders and members, and (iii) organisational culture and environment on creativity is undertaken. Practical advice is derived from literature findings wherever possible.

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Keywords: creativity, innovation, research, development, motivation, organisational culture, brainstorming

1. INTRODUCTION

There is general consensus that high profit companies of our times rely heavily on innovation to maintain their efficiency and survivability, with innovation being defined as the process from an idea to the introduction of a novelty into the market (Mumford 2000, Basadur 2004). Novelty and usefulness are in fact the two characteristic parameters to differentiate true innovations from me-too products and purely artistic achievements (Ford 1992, as cited in Scott 1995). Although an innovation is often a technologically different (and, in the best case, superior) product, it may also take the form of a new design, service or business process (Mumford 2000).

Creativity, which we define as the combination of idea generation and idea validation (see section 2.2), is essential to the innovation process. Again and again, novel ideas need to be incorporated into the innovation process (figure 1). Creativity is even necessary before the actual innovation process can begin, and can thus be considered as "pre-innovation": Although the first idea itself might be elusive, it is prerequisite for scientific, technological or procedural innovation.

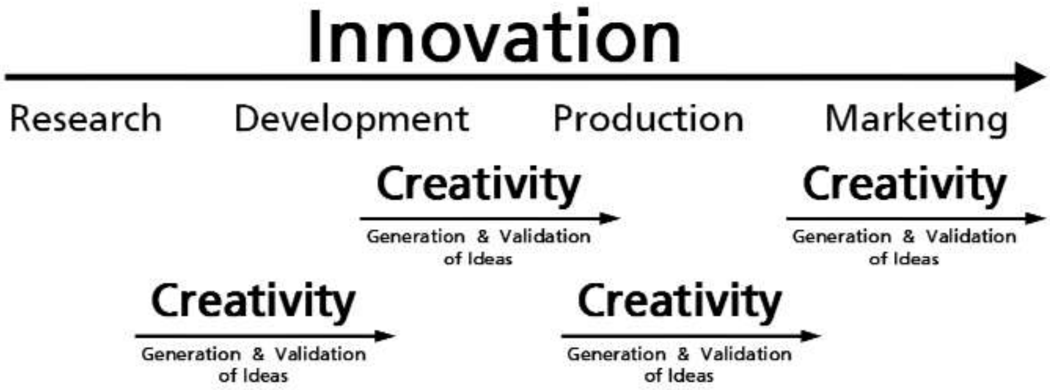

Figure 1: The relationship of innovation and creativity

Shalley & Gilson (2004) state that "most managers would agree that there is room, in almost every job, for employees to be more creative." Although we generally agree with this view, creativity seems to be more important in some work domains than in others. While creativity is a sine qua non in advertising and marketing, it might be less desirable in accounting, although a novel accounting process can well be a valuable innovation. Most scientific and technological innovation is expected to originate from research and development (R&D) organisations or departments. As creativity is the source of innovation, it can well be claimed that creativity is essential for successful R&D and that creativity in R&D thus deserves special attention. According to Heinze (2007) there are five types of scientific creativity:

1. Formulation of a new idea (or of a set of new ideas) that opens up a new cognitive frame or brings theoretical claims to a new level of sophistication (basic assumptions → theory, e.g. Einstein's theory of specific relativity)

2. Discovery of a new empirical phenomenon that stimulates new theorizing (observation → theory, e.g. Darwin's theory of evolution)

3. Development of a new methodology, by means of which theoretical problems can be empirically tested (theory → method, e.g. Spearman's development of factor analysis to test his theory on mental abilities)

4. Invention of a novel instrument that opens up new search perspectives and research domains (technique → new possibilities, e.g. scanning tunnelling microscopy which made nanotechnology possible)

5. New synthesis of formerly dispersed ideas into general theoretical laws enabling analyses of diverse phenomena within a common cognitive frame (single ideas → general theory, e.g. general systems theory)

All of these types of creative acts are achievements in their own right. Their diversity cautions against a definition of scientific creativity that is too narrow to reflect this range. Another danger in the study of creativity is to focus only on exceptional persons and events (like the examples in the above list). Although the study of exceptional persons or events might cast an interesting light on creativity in general (Holm-Hadulla 2007), it appears to be more useful to concentrate on average people. We propose that in normal circumstances the development of creativity in ordinary employees is a more feasible way of inducing idea generation and validation than hiring or nurturing a genius, as by definition a genius is the great exception. Moreover, there is another problem in the study of singular "geniuses", especially in the field of basic sciences. There is little doubt that chance has played a major role in many breakthrough discoveries. Historic examples are the discovery of the vulcanization of rubber by Charles Goodyear (which is reported to have happened the first time on a dirty lab floor in 1839), radioactive radiation by Henri Becquerel (while studying a faulty theory of phosphorescence in 1896), and Penicillin by Alexander Fleming (working with fungus-contaminated Petri dishes in 1928). The creative act of these researchers was to recognise the importance of unexpected findings, and what made them succeed was their determination to find the reason why something had gone wrong. On the other hand, if these "accidents" had happened in other laboratories, we would probably study other "scientific geniuses" nowadays (although Simonton (2004) remarks that some scientists "appear to be consistently more lucky than others", implying a special ability to exploit chance). The risk of studying champions that were "just lucky", and ignoring brilliant, but less fortunate scientists is reduced when looking at larger groups of more average people. This paper summarises the literature in the field of work place creativity, with special attention given to the R&D environment. Though our aim was to focus on recent research, some older papers have been considered if they have proven to be the foundation of further fruitful work. As for structure, we will first outline some theoretical concepts of creativity, then analyse motivation - maybe the most important factor for individual creativity- , move on to creativity on team or work group level, and finally point out measures to be taken on institutional level to create an environment favourable to the generation and validation of new ideas.

2. MODELS OF CREATIVITY

The theoretical models of creativity currently discussed in literature can be divided into two groups: componential theories that examine which human characteristics and abilities are necessary to perform creative acts, and sequential theories that concentrate on the creative process. As both kinds of reasoning lead to interesting insights, examples of both are discussed below and referred to throughout this paper. Generally speaking, componential theories give advice on how to design long-term processes conducive to creativity, while sequential theories are more useful when considering short-term action or interaction.

2.1. The "Componential Theory of Individual Creativity"

According to the Componential Theory of Individual Creativity (Amabile 1997), the three essential components of individual creativity are expertise, creative-thinking skill and intrinsic task motivation. Expertise comprises factual knowledge, technical proficiency and a special talent in the target work domain. While knowledge and proficiency can be improved over time, talent is more or less a given thing rooted in individual personality. Creative-thinking skill is that "something extra" found in creative people. There is a consensus that creative thinking can be learned, at least to some degree. Basadur (2004) emphasises that idea generation should be separated from idea validation, and claims that this deferral of judgment can be trained. A "master-apprentice relationship" is generally considered to be most effective for the teaching of creative-thinking skills (e.g. Weilerstein 2003). Motivation determines what a person actually will do. As motivation is the component that can be influenced most directly by environmental factors, it will receive special consideration in section 3.

2.2. Sequential models

There are several models that describe the creative process in a sequential way. According to Wallas (1926) the four stages in the development of an idea are: preparation, incubation, illumination, and verification. Preparation comprises both personal preparation (knowledge and proficiency) and the investigation of the problem in all directions. Incubation is a period in which the problem is banned from conscious thought, and dealt with in an unconscious way. Illumination is the appearance of the "happy idea". This can be either instantaneous or a slower process. These two, somewhat mystic, stages mentioned last can hardly be influenced from the outside. Verification, finally, is the testing of the validity (novelty and usefulness) of the idea, either by the creator or different persons (cited from Scott 1995 and Holm-Hadulla 2007). In contrast to this rather abstract four-stage model, we describe the creative act as being composed of only two stages, both of which can be influenced on individual and institutional level. The two stages are idea generation and idea validation. While idea generation requires divergent thinking skills to produce as many and as diverse ideas as possible, in idea validation convergent thinking skills are necessary to decide which are the most promising ideas. A similar process, "ideation-evaluation", has been described to be essential to the three stages of the problem solving process (problem finding, problem solving, solution implementation) by Basadur, Graen & Green (1982). In artistic settings, the first step is a value in itself and validation is not that essential, as loose ends might even be desirable in a work of art. In commercial or scientific settings, validation is absolutely necessary as only very few ideas can be taken to realisation. Both stages can either be performed by one individual or as a group process.

2.3. The "Search for Ideas in Associative Memory" (SIAM) model

In the theoretical section of their paper, Nijstad & Stroebe (2006) describe a creativity model called Search for Ideas in Associative Memory (SIAM). They claim that two distinct types of memory are active in the creative process, i.e. a large, static network of associative images (Long-term Memory (LTM), Note: In this context, "images" are general intellectual objects with no necessity of visual or spatial components) and a small, dynamic Working Memory (WM) (closely associated with consciousness). Based on this assumption the generation of an idea is described as to proceed in several steps (figure 2):

1. Based on the given task, a search cue is generated in the WM. This takes some conscious effort.
2. The search cue activates an image in the LTM. The choice of which image is activated is not deterministic.
3. If no image can be activated or if the activated image has already been activated previously in the process, this is considered a "failure", and a new image has to be activated. If the number of failures exceeds a certain limit, the whole process is terminated. (negative feedback loop 1 → "running out of ideas")
4. If the image activated in step 2 is "new", the association between this image and the original problem is strengthened.
5. Next, an idea is created from the image, either by combination of different parts of the image, or the image and the cue, or the image and previously generated ideas. This is, again, a probabilistic process.
6. If no idea can be generated or if the generated idea has already been generated previously in the process, this is considered a "failure", and a new idea has to be generated. If the number of failures exceeds a certain limit, a new image has to be activated. (negative feedback loop 2 → "image depleted", search cue may be modified by considering new ideas)
7. If the idea generated in step 5 is "new", the associations between this idea and the image and between the idea and the original problem are strengthened.
8. Next, the idea is stored in the WM, and, if no disturbance arises, expressed.
9. A new idea is generated → step 5

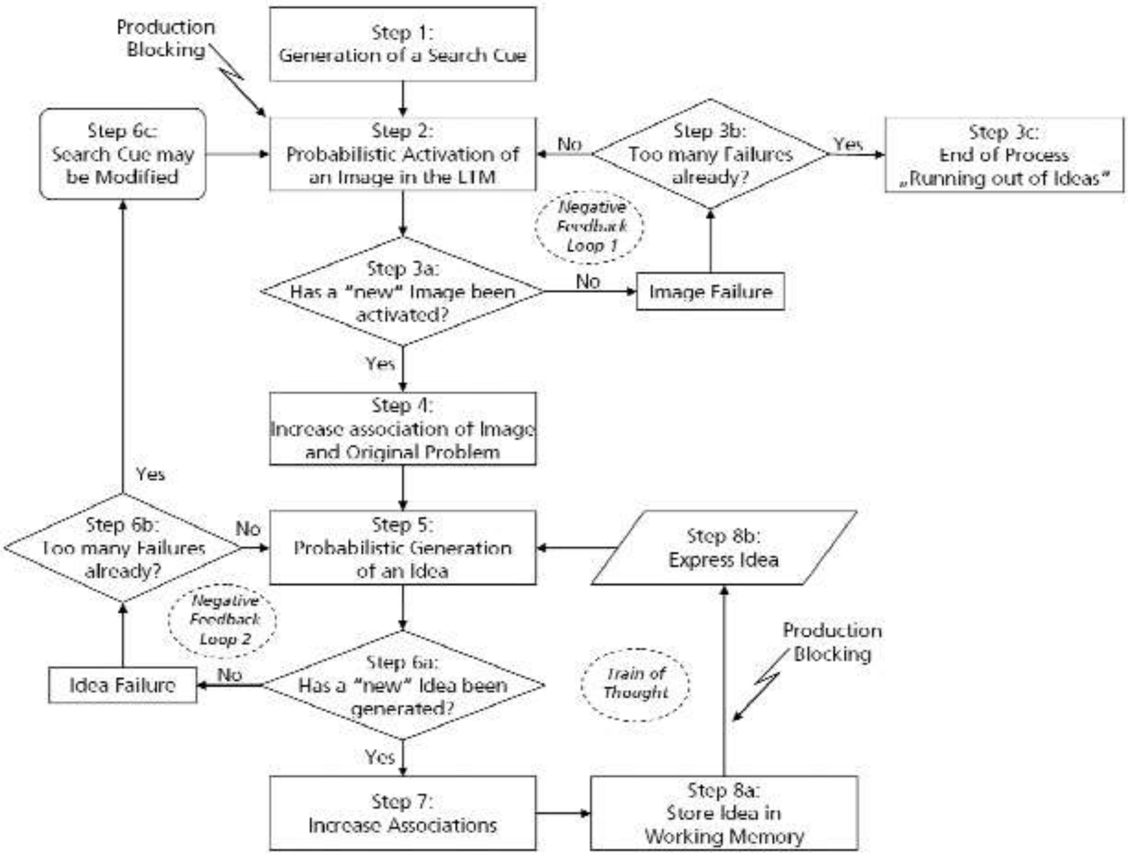

Figure 2: The "Search for Ideas in Associative Memory" (SIAM) model (adapted from Nijstad & Stroebe (2006))

The Search for Ideas in Associative Memory (Nijstad 2006) matches well with the Componential Theory of Individual Creativity (Amabile 1997): Expertise can be considered a measure of how well developed (density and ontological interconnectedness) the LTM is, creative-thinking skill can be seen as proficiency in cue generation and activation of images, and motivation as tolerance to failures and thus a measure on how long the ideation process is kept active.

2.4. SIAM and production blocking

According to Nijstad & Stroebe (2006), production blocking, a concept important in the explanation of effects observed in brainstorming (see section 4.3), may occur at two stages of the process. In both cases it is caused by the limited resources of the WM. There is a high chance of a validated idea being simply forgotten if mental work has to be performed between storing the idea in the WM (step 8a) and expressing the idea (step 8b). In a group brainstorming setting, this mental work consists of monitoring the group proceedings for a possibility to express one's idea. The chance of forgetting an idea rises with waiting time, and thus with group size, making large brainstorming groups less effective. Apart from that, this mental work might also interfere with the demanding process of activating a new image in the LTM (step 2). The false impression that group brainstorming is more effective than individual brainstorming might be caused by these interruptions (at least in part, as other processes like social comparison play a part, too): In individual brainstorming, both more images are activated, and activated images are used more thoroughly, as fewer interruptions occur. That leads to a higher number of "failures", which again are experienced as negative, and lead to the (erroneous) feeling of low efficiency.

3. MOTIVATION

Although most of the relevant publications emphasise that innovation is a group process, Redmond (1993) underlines the fact that "it should, however, be recognised that the individual is the ultimate source of any idea or novel problem solution". Although this original idea will be modified, supplemented or excluded by a team, idea generation happens inside the individual. On the other hand, idea processing can only happen once the idea is expressed and communicated to the outside environment. As pointed out above, the Componential Theory of Individual Creativity (Amabile 1997) insists on (intrinsic) motivation as a key component of individual creativity. The link between motivation and creativity is well established and generally accepted. Yet, there are two questions related to it that have not been answered exhaustively. The first one has received some attention, and results from research on it will be discussed further on: Does it make a difference if individuals are motivated by themselves (intrinsic motivation), in contrast to being motivated by prospects of receiving rewards for being creative from outside (extrinsic motivation)? The second question has not been raised in a scientific context, to the best of our knowledge: Does motivation really influence the production or just the expression of new ideas? In other words, do poorly motivated individuals have new ideas at the same rate as highly motivated ones, and do they just not tell anybody?

3.1. Intrinsic vs. extrinsic motivation

Arthur Schawlow, winner of the noble prize in physics 1981, was once asked what, in his opinion, made the difference between highly creative and less creative scientists. He replied: "The labor of love aspect is important. The most successful scientists often are not the most talented. But they are the ones who are impelled by curiosity. They've got to know what the answer is" (cited by Amabile 1997). This is a fair description of intrinsic motivation. Another example is given by Akio Morita (1986), the founder of Sony: "I believe people work for satisfaction. I believe it is a big mistake to think that money is the only way to compensate a person for his work. People need money, but they also want to be happy in their work and proud of it." This sense of pride (which seems to be closely associated with the sense of ownership mentioned in other studies) is another component of intrinsic motivation. It seems to reflect a genuine human longing to be creative and to be identified with the creative act or outcome. While there is little doubt that intrinsic motivation is typical of highly creative individuals, the question if and why this type of motivation could be more conducive to creativity than motivation induced by the prospect of some kind of reward is still discussed vividly: Several authors claim that incentives and other measures that let employees participate in commercial success, will motivate creativity (e.g. Springer 1992), while others observe that creativity is dwarfed if rewards are promised (e.g. Amabile 1996). To make things even more complicated, a third kind of motivation, by feelings of obligation, has been proposed (Cooper 2006). Baer et al. (2003) aimed at resolving the confusion caused by these inconsistent findings on the effects of rewards on creativity. They put forward the idea that the effect of rewards on creativity is influenced both by cognitive style and work complexity. Cognitive style is defined by the Adaption-Innovation Theory (Kirton 1994), in which "adaptors" tend to operate within given paradigms and procedures, while "innovators" tend to develop problem solutions that are qualitatively different from previous ones. After evaluating interviews with 117 employees of two manufacturing companies and correlating the results with creativity as perceived by immediate superiors, Baer et al. (2003) were able to show a complex pattern between cognitive style, job complexity, and the effect of rewards on creativity (figure 3). They found that employees with simple jobs showed a strong response to extrinsic rewards: While the creativity of innovators was lowered, adaptors showed a steep rise in creativity, reversing the original order of innovators being more creative than adaptors. Their main finding in respect to complex jobs, which are predominant in R&D environments, was that while innovators are hardly affected by the prospect of rewards, the creativity of adaptors is considerably lowered. This was explained by pointing out that adaptors in complex jobs have weaker intrinsic motivation, which is further shaken if extrinsic reward is offered, as this makes them feel even more instrumental for making profit and less valued as individuals. We are not totally convinced that this is the only possible explanation of these interesting findings.

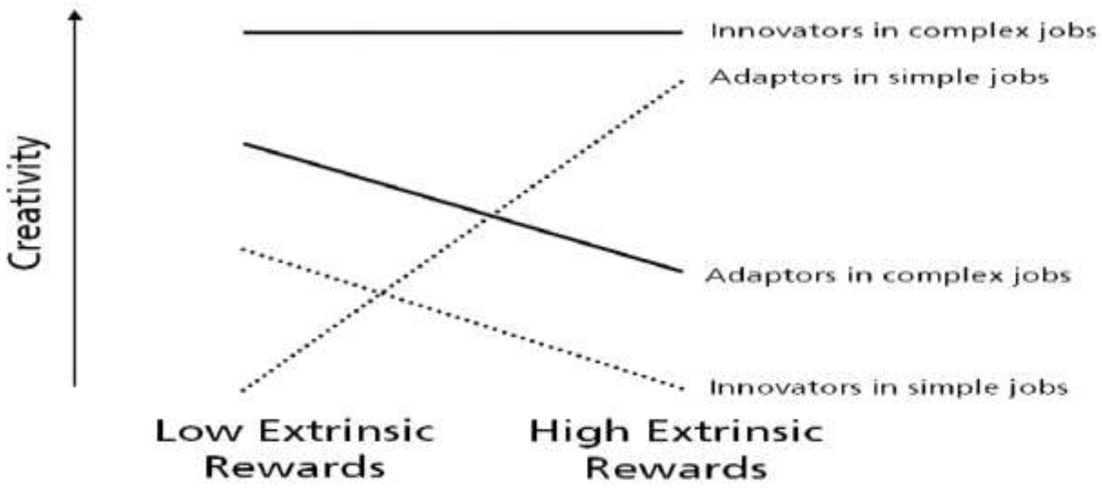

Figure 3: The relationship between creativity and rewards (adapted from Baer et al. (2003)

According to Mumford (2000) a combination of extrinsic and intrinsic rewards might be the most effective way of boosting creativity: "Because creative work is linked to curiosity and independence, providing time to pursue topics of personal professional interest, or reducing administrative burdens, may prove useful reward strategies particularly when accompanied by pay incentives, bonuses, and patent rights." Rewards and incentives have an additional benefit: They indicate to employees what kind of performance is desired by the management and are thus valuable means of communicating corporate values and goals to individual employees (Wong 2003). As such, they support the immediate superior's function of conveying these values and goals (see section 4.2). In contrast to this, Heinze (2007) observed that many research institutions run reward schemes that work in a detrimental way: "Institutional arrangements for rewarding outstanding scientists include increasing the size of their research group, putting them in charge of a research institute, or expecting them to act as a national expert on various committees. These rewards have the perverse effect of preventing these scientists from doing what they are best at: research and inspiring colleagues." These observations urgently call for a critical evaluation of incentive systems especially in highly innovative areas like R&D where the reward schemes described by Heinze are common and unquestioned practise.

3.2. Mission

A less individualistic approach towards improving motivation is the provision of a "mission". The perception of contributing a unique part to the achievement of a worthy goal (like "curing cancer" or "flying to the moon") has been identified as a major element in most of the creative events examined by Heinze (2007). According to Akio Morita (1986), it is one of the prime tasks of management to find and communicate these overall targets: "Management of an industrial company must be giving targets to the engineers constantly; that may be the most important job management has in dealing with its engineers." The same is surely true for scientists. Some research has been conducted on how such overall goals or missions can be generated. In a model suggested by Strange & Mumford (2005), the analysis of idealized goals and their causes is prerequisite for the formation of a so-called prescriptive mental model (PMM), which is a set of ideas on how things should be. This PMM is then refined to a "vision" that can be communicated, and may thus inspire others to act in a way favourable to reaching the state imagined in the PMM. A vision in this sense can be distinguished from a plan, as it tells people where to go but does not necessarily tell them how to get there. Interestingly, Strange & Mumford (2005) have found that experience plays a major role in creating such mental models. They claim that having people with a wide range of experience and a "colourful" background in the team will benefit the creation of "vision" and thus contribute indirectly, but very effectively to enhancing creativity.

3.3. Contest

Several highly creative scientists interviewed by Heinze (2007) claimed that friendly competition between different groups of the same organisation had been important as a driving factor towards creative achievements. Priority races between groups of different organisations might also be strong motivators. These priority races can take the form of friendly competition with a high level of communication or of fierce rivalry with no mutual communication at all, while anything in between is also possible. Motivation can also be improved on inter-company or even international level: A study conducted under the auspices of the US National Academy of Engineering (1999) concluded that inducement prize contests have led to innovations in engineering (especially aeronautic engineering) in a highly effective way. This positive outcome is attributed to three effects: (i) the ability to attract a broad spectrum of ideas and participants, (ii) the potential to leverage financial resources from sponsors, and (iii) the capacity to educate, inspire and mobilise the public (as cited in Young 2007). Recent examples of this kind of contests are the Ansari X-Prize for the first non-government organisation to launch a reusable manned spacecraft into space twice within two weeks (won on October 4, 2004 by Scaled Composites and their "SpaceShipOne") and the DARPA Urban Challenge 2007 for an autonomous vehicle crossing an urban environment (won on November 3, 2007 by Tartan Racing's vehicle "Boss").

4. WORK GROUP CREATIVITY

In remarkable contrast to the rapid technological progress in the last decades, the process by which technological innovation is performed has remained fairly un-changed over the years: R&D is mainly carried out by project groups that generate or import scientific and technological information, transform it into novel ideas, products, or processes, and then export these innovations to other units of the organisation (Elkins & Keller 2003). So, while creativity is sometimes still associated with the "lone genius" working in a secluded laboratory, most creative work takes place in organisational settings and is usually conducted in teams nowadays (Redmond 1993). Going one step beyond, Fischer et al. (2005) claim that most intellectual processes, including creativity, are in fact social processes. According to them, "the power of the unaided individual mind is highly overrated" and "most scientific and artistic innovations emerge from joint thinking, passionate conversations and shared struggles among different people, emphasizing the importance of the social dimension of creativity." This emphasis on group work is based on the assumption that idea generation is best performed in groups and that interaction with others fosters creativity (Vester 1978). Yet, some researchers challenge this view and assert that contrary to popular belief, group interaction inhibits the ideation process (e.g. Nijstad 2006). In the light of controversies like this, it seems to be prudent to examine group interaction processes, both inside the group (including interaction with group leaders), and between groups and their surroundings, in order to gain insight into creative processes in working environments. We will examine processes of work group creativity under various aspects: (i) size and constitution of the group, (ii) impact of the group leader, and (iii) creativity techniques.

4.1. Size and constitution of the work group

While large groups offer the advantage of providing a large knowledge base, especially if group members come from different professions, there is a consensus among researchers that small groups are more apt to perform creative tasks. The mechanism behind the effects blocking creativity in large groups is quite complex. One aspect is losing track of "who is doing what", which in turn will lead to a reduced spread of novel ideas. Large groups are also less conducive to "master-apprentice relationships", which are considered exceptionally well suited for passing on creative abilities from senior to junior members of staff (Weilerstein, Ruiz, Gorman 2003). This kind of relationship is mutually beneficial, as senior staff is likely to get fresh ideas from newer members of the team: "The wellsprings of research creativity reside in junior scientists and are waiting to be unleashed" (Heinze 2007). Furthermore, collaborative peer review, most often by a more senior scientist, is considered the best method to direct creative work, when requisite expertise and motivation are present (Mumford 2000). In larger groups, communication needs to be formalised and thus requires complex and time-consuming meeting procedures in contrast to low-level chats typical of smaller teams. In these less formal chats new ideas arise at a considerably higher rate. Regular, large meetings with a strict hierarchical order can even be considered as a means of suppressing creativity since they have the well-documented effect of weakening innovative ideas by voicing all kinds of concerns and limitations. They will thus level down novel ideas to a streamlined generally accepted consensus. Additional scarceness of administrative staff will add to the low effectiveness of these meetings, as preparation will be poor which makes the outcome even more erratic. As a practical solution to the dilemma that small groups are more conducive to creativity, but lack the knowledge and ability base of larger groups, Heinze (2007) suggests to organize research in small teams, but to create an organisational environment that facilitates informal interaction of these small teams (see section 5.3). These interactions are considered to be especially fruitful if groups have highly complementary knowledge and expertise, e.g. if theoretically focused groups interact with more experimentally oriented ones. In such a context, the small "core teams" can be considered as Communities of Practice (CoP), held together by a shared knowledge base and a homogeneous modus operandi (set of methods and techniques), while the whole organisation can be considered a Community of Interest (CoI), held together by a common goal. Smaller CoIs, made up of members of different CoPs, can be formed as the necessity arises. They are less stable than the core teams and might disband after a particular problem has been solved, be it after five minutes or several years. The question whether constant or changing teams are more conducive to creativity has caused some debate among scientists. Nemeth & Ormiston (2007) claim that stable group membership might well increase morale, performance and felt creativity, while measurable creativity flourishes in a less comfortable environment with changing group members. People exposed to dissent, which stable groups appear to actively discourage, take account of more information on all sides of the issue, utilise multiple strategies, have improved performance and make better decisions (Gruenfeld, 1995; Van Dyne & Saavedra, 1996, both as cited in Nemeth 2007). As one conclusion Nemeth & Ormiston (2007) state that perceived creativity may have little to do with actual creativity. They suspect that people often confuse friendliness and comfort with creativity. The discrepancy between felt and measurable creativity shows parallels to the effects of group brainstorming (as described in section 4.3), and indicates that self-assessment of creativity is always precarious. This is supported by Scott (1995) who advises to set generous but strict deadlines to creative projects, as highly creative people are rarely satisfied with the outcome of their efforts. Nemeth & Ormiston (2007) conclude: "Managers should be cautioned against the 'paradox of success' wherein they place individuals in groups on a new task based on who previously worked well together. Rather, teaming individuals who have not previously worked together may better benefit the creative process." There is considerable evidence that introducing new members with a background different from the one already existent in a team will lead to higher creativity. Leaders with the ability to select new group members with skills complementing the ones already present are considered to obtain the most creative groups in a scientific environment (Heinze 2007). These new members should share some domain knowledge with present members to make effective communication possible, but they should also bring new abilities to the group to broaden the team's domain coverage. These features can be depicted both as a fish-scale model (Fisher 2005) and as a Venn diagram (Simonton 2004) (figure 4). Both diagrams show that new members should broaden the horizon of the existing group, while still covering enough common ground to be able to communicate with other team members. Springer (1992) recommends considering individuals with a less-than-streamlined CV when hiring for creativity, as experience in diverse fields is a productive source of creative thought.

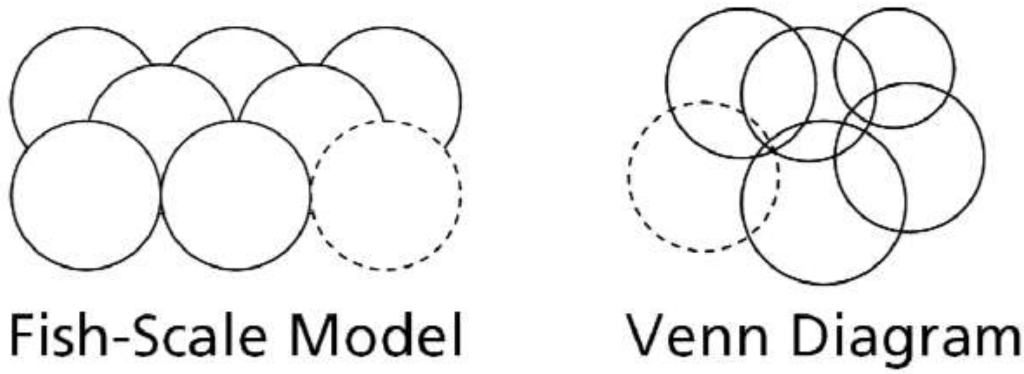

Figure 4: Different graphical representations of suitable knowledge within work groups (circles: knowledge domains of individuals; dashed circles: well suited domains of new group members)

4.2. Influence of leader behaviour

The influence of leader behaviour on creativity in subordinates is well documented in literature (e.g. Redmond 1993, Wong 2003, Amabile 2004). A principal function of leaders is to set goals and assign tasks. In the case of highly skilled workers, like scientists or engineers, a special sensitivity is necessary, as both too much and too little guidance will impair creativity and productivity. Personal freedom, both in choosing which particular task to do next and how to tackle it, has been identified as a major source of creativity by various authors (e.g. Schepers & van den Berg 2007). Freedom of choice in how to conduct their research was one of the points stressed most when creative scientists were asked about the source of their creativity (Heinze 2007). This freedom also makes employees feel that they are indeed valued as persons, a factor that - according to Springer (1992) - leads to well-being and thus stimulates creativity. Goals and objectives should be defined in broad terms to guarantee the necessary procedural freedom. Goal definition should focus on creativity rather than on production, as highly creative work is often less productive in terms of measurable output than more conventional one (Mumford 2000). Shalley & Gilson (2004) underscore this view by stressing that time is a critical resource when managing for creativity. They point out that it is far easier and less time consuming for most employees to stick to routine methods that have proved to be efficient than to spend considerable time and energy on new, creative approaches whose final outcome is rather unpredictable. After studying the influence of leader behaviour on the quality of the solution of a marketing task, Redmond, Mumford & Teach (1993) suggest that although "the pressures of organisational life may cause leaders to seek and demand immediate problem solutions, […] leaders would be well-advised to give subordinates time to think about the problem." Leaders should "actively take steps to encourage subordinate problem construction", e.g. by having them list multiple issues or restate the problem. Basadur & Gelade (2006) give several examples where insufficient time spent on problem generation caused substantial delay in finding viable solutions. Immediate superiors are thought to have the strongest impact on employee motivation. They have a central mediating role between the organisation and the individual employee. It is their task to communicate the values of the organisation and to serve as visible role models on how employees are supposed to act. In doing so, they reconcile the dichotomy between what employees would like to do and the actual work that the organisation expects them to do, without over-controlling highly skilled subordinates. Another important function of group leaders is to connect the work group to the outside world. This means communicating the group's needs, aims, and results to higher-level management and, especially in the case of academic research, to a broader scientific community. On the other hand, it is the group leader's function to act as an information broker to connect the group to other interested parties that might provide physical or intellectual means not available to the group otherwise (Heinze 2007). The perception of a leader that supports the team in these ways, combined with respect and (public) recognition for individual group members, have been shown to be among the strongest motivators for high ability subjects who found their task involving and meaningful (Amabile 2004). The inducement of self-efficacy (e.g. by appreciating individual potential or achievement) and the motivation of subordinates to apply time to problem identification and goal definition should also be mentioned. These factors have been identified as having positive effects both on the quality of work output and on the willingness to take creative risks (Redmond 1993). Finally, examples of both positive and negative behaviour reveal that the positivity or negativity was often conveyed more by how something was done than by what was done. This means that leader actions that are conducive to creativity, like serving as a good work model, planning and setting goals appropriately, supporting the work group within the organisation, communicating and interacting well with the work group, valuing individual contributions, providing constructive feedback, showing confidence in the work group, and being open to new ideas, might not be enough if they are perceived as mere management tactics by employees. In the same way that interest in one's work is highly motivating (see section 3.1), the perception of genuine interest of the leader in the team and its individual members is a strong creativity enhancer that cannot be substituted by the mechanical application of simple motivation techniques. The study of this effect is complicated by the fact that leaders' behaviour patterns can lead to positive or negative spirals in team dynamics and performance, whereby the effects of leader behaviour become amplified over time. This suggests that the effects of leader behaviour on subordinate perception, emotion, and creativity are neither static nor unidirectional, but part of a dynamic relationship (Amabile 2004). In the end, "what seems to be called for is an open, intellectually challenging environment where entrepreneurial behaviour on the part of collaborating teams is actively encouraged" (Mumford 2000).

4.3. Creativity techniques

Creativity techniques like brainstorming are generally considered useful tools for idea generation. Yet, Nijstad & Stroebe (2006) caution against their undiscriminating use in groups. They cite considerable evidence that while the general rules of brainstorming (emphasis on quantity, encouragement of unusual ideas, and discouragement of criticism) are well suited for producing high quality ideas, "the prediction that brainstorming is best performed in groups has not received support." While felt creativity is higher if brainstorming is performed in a group with n members, the measurable outcome is higher if creative tasks are performed by n individuals and ideas are then pooled ("nominal group"). By reviewing the literature (e.g. Mullen 1991), Nijstad & Stroebe (2006) were able to show that indeed "productivity loss in brainstorming groups is highly significant, and of strong magnitude." As a consequence, they recommend the use of this technique either for individual idea generation or in two-person groups, as the loss of productivity increases rapidly with group size. Production blocking, that is stopping the transition from having an idea to expressing the idea, seems to be the main mechanism behind this negative effect. It correlates with group size, as the individuals have to wait for their turn to express an idea until other group members have expressed their thoughts (Nijstad 2006). "Electronic brainstorming" (EBS) has been proposed as a creativity techniques that avoids this kind of forced break and can lead to improved idea output, especially in large groups. Although several different methods of EBS exist, most share a user interface consisting of two windows, one to type in ideas, and another to display all ideas generated in the particular session. DeRosa, Smith & Hantula (2007) have conducted a meta-analysis to evaluate the possible benefits of EBS. According to them, EBS could have several positive effects, as compared to traditional face-to-face (FTF) brainstorming:

(i) production blocking should be less pronounced, as the individual group members can type in a new idea at any time, without having to wait for their turn, (ii) EBS has an inherent memory advantage, as ideas are conserved and remain visible on the computer screen, (iii) the anonymity possible in EBS might facilitate the expression of dissenting and minority opinions, which again stimulates thinking in divergent ways and finding creative solutions (Nemeth 2007). As to the quantity and quality of ideas, DeRosa, Smith & Hantula (2007) were able to place EBS between FTF brainstorming and nominal control groups: While outperforming traditional brainstorming groups by far, EBS groups were slightly less productive than the nominal controls, where the individual ideas were pooled without interaction. As to member satisfaction, EBS outperformed both other kinds of brainstorming, possibly because the results were so clearly visible on-screen. Taking the meta-analysis one step further, the influence of group size was analysed separately, with surprising results: While small nominal (non-interacting) groups outperformed EBS groups with eight members or less, larger EBS groups showed considerably better performance than their nominal controls. As for practical considerations, DeRosa, Smith & Hantula (2007) advise to use EBS instead of FTF if group brainstorming is desired. They believe that the size effect is only of practical importance if it is relatively easy and inexpensive to form large groups or teams. In any other setting, individual brainstorming and pooling of ideas might well be more efficient. While brainstorming, as the classical creativity technique, still receives considerable research interest, other group techniques have evolved. Many of those applicable to small groups (in contrast to large group distributed design tools) deal with the externalization of knowledge. According to Fischer et al. (2005) externalization, that is the expression of otherwise tacit knowledge, supports group creativity in several ways: (i) to express a vague mental concept it has to be made more concrete, making thoughts and intentions more accessible for reflection, (ii) a physical record of mental efforts is produced, inhibiting the forgetting of ideas and conveying a higher feeling of productivity, (iii) it relieves from the difficult task of thinking about ones own thoughts, (iv) others can act on and react to externalized ideas, and (v) it contributes to a common language of understanding, a way to speak about things. The use of computers to support externalization of knowledge is becoming increasingly common. Interestingly, many of the supporting methods involve moving physical objects like Lego bricks. This seems to be a very "natural" way to discuss problems in groups that helps experts from different domains to interact in a meaningful way (Fischer 2005).

5. THE CREATIVE INSTITUTION

Most group creativity takes place in the context of larger organisations, be it pure research institutions or commercial enterprises with R&D as one department among others. While the size of an organisation might be less important for non-experimental work, a large, well-endowed working environment able to support an extensive array of instruments and workspaces is indispensable for experimentally oriented scientific or engineering work. As suggested above, the ideal organisational setting for creativity seems to be a large, highly diverse institution where small groups can easily interact and profit from each other's views, abilities and knowledge domains. In this section, some conditions that are conducive for creativity in such an organisation are examined.

5.1. Organisational culture

Organisational culture has been defined as "a guideline or pattern of regular and predictable activity, formed by a series of coordinated actions that are put into practice before a specific problem or stimulus" (Claver 1998). In other words, it describes the way that an organisation deals with problems, and indeed, what kind of problems it deems worthy dealing with. According to Cameron & Quinn (1999), the culture of organisations or their departments can be represented as the four quadrants of a system formed by the two axes "introversion – extroversion" and "flexibility – control" (figure 5). Introversion represents care for people and efficiency, while extroversion reflects awareness of the organisational environment. Flexibility is linked to adaptation and change, whereas control reflects orientation towards top-down management and the application of formal rules and prescriptions. A striking feature of this system is that though the concepts at the extremes of the axes are incompatible, neither concept is per se superior to the other. The four organisational cultures represented as quadrants are coined Clan (flexibility & introversion, a culture that seeks to please its members), Adhocracy (flexibility & extroversion, a culture that seeks to broaden its horizon), Market (control & extroversion, a culture that seeks to get things done), and Hierarchy (control & introversion, a culture that seeks to ensure stability).

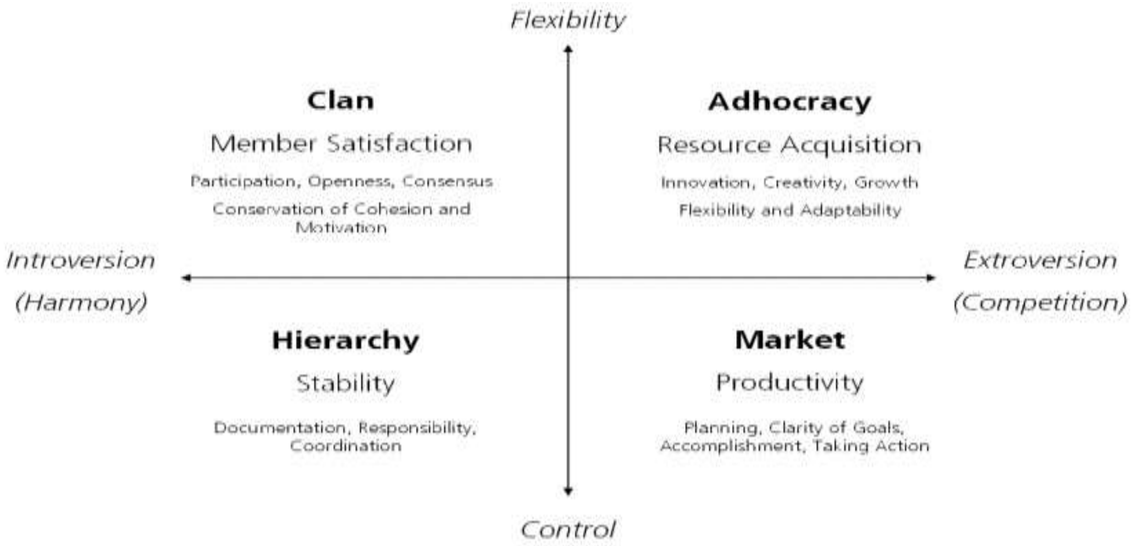

Figure 5: Organisational cultures (adapted from Cameron & Quinn (1999))

According to Claver et al. (1998), the ideal profile for creativity is Adhocracy: Openness for new technologies (and change in general) and the readiness to take risks, both factors these authors identify as creativity-promoting, are part of the ideals and values immanent to the Adhocracy culture. The flexibility to react rapidly to new developments, to incorporate new technology, and to address new problems and ideas as they arise, has also been found to be typical of highly creative research groups (Heinze 2007). It is therefore advisable to create an Adhocracy type environment if high creativity is desired, while alternative corporate cultures might be more valuable in other parts of a larger organisation. Typical features of a Hierarchy are well-established procedures and adherence to strict rules. They are clearly detrimental to the establishment of an Adhocracy and should thus be avoided in an R&D setting. A willingness to take risks has already been mentioned as conducive to creativity several times. It thus seems fitting to consider the risks posed by a creative approach to problem solving. The main risk in taking a new path lies in abandoning a well-trodden one. This has to be done at a point in time when it is not clear where the new path might lead to. The dilemma that novel, high potential methods perform worse than long established concepts and procedures has been addressed by Young (2007). It seems to be a general rule that in the beginning new methods have poorer performance than well-established procedures. On the other hand, they have the potential to result in higher performance, if enough effort and time are invested (figure 6). This is inherently associated with considerable risk, as it is not clear what the potential performance of the novel method is: The chances that it will never exceed the established, by-the-book procedure are considerable. In that case all the invested means and efforts were futile. Practically, this risk can lead to the effect that "negative stereotypes and immediate work demands can lead to a premature rejection of potentially valuable new ideas," if no sufficient emphasis is put on the introduction of novel ideas as a management principle (Mumford 2000). Again, it seems to be essential to define "success" in a way that allows creative failure to be considered a necessary step on the way to improved performance.

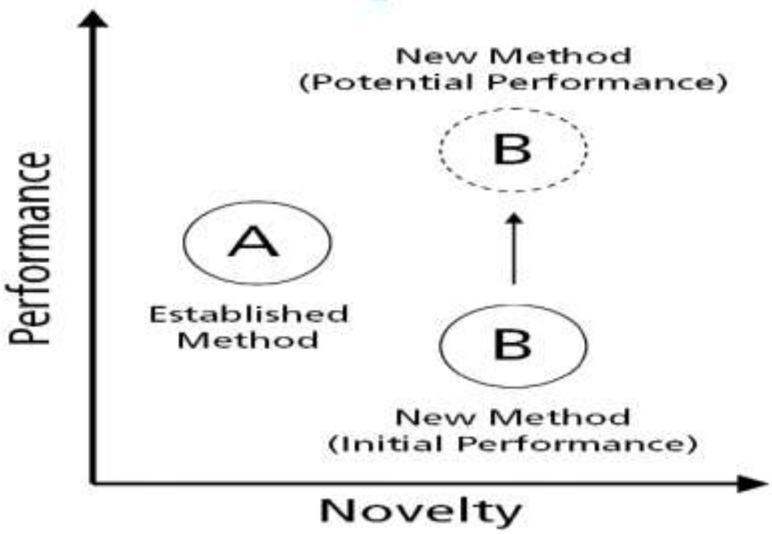

Figure 6: A risk associated with creativity lies in the unknown potential of method B (adapted from Young (2007))

Since R&D has a time-lagged, sporadic, and non-market nature in relation to its outputs its success is hard to evaluate by standard measures like turnover or revenue (Elkins & Keller 2003). This might be the reason why organisations with a strong financial focus (Market type culture) tend to be less innovative than strategically oriented enterprises. In Market type organisations, incremental innovation can be viable, while the introduction of more radical ideas might require the creation of new divisions, spinning off part of the company or licensing the technology to other enterprises (Mumford 2000). Apart from that, market-oriented cultures will prefer stable groups, as the efficiency of well-rehearsed teams is considerably higher than that of ad-hoc groups, which in turn exhibit a higher output of creativity (see section 4.1). The introverted nature of the Clan makes it less apt for creative work, at least in a technological sense. Fisher et al. (2005) emphasise that integrating diversity, making all voices heard, and valuing openness and transparency, all features typical of a Clan, are highly beneficial for the development of social creativity. This creativity, however, is introverted, and might not be interested enough in what is happening in the outside world to actively develop solutions for real world problems. On the other hand, this tendency to ponder on its own issues makes the Clan very apt for the production of artistic outcomes, where usefulness is not of paramount importance. Finally, it has to be noted that the individual perception of organisational culture has a higher influence on employees' creativity than the actual, objective work environment (Schepers 2007). Again, it is "in their heads" where creativity starts, and environmental factors will only influence their state of mind in an indirect way.

5.2. Employee perception of environmental conditions

To determine the social factors of work-environment creativity, Schepers & van den Berg (2007) evaluated 154 questionnaires completed by employees of the Civil Engineering Division of the Dutch Ministry of Transport. They sum up their results by stating that work-environment creativity is predominantly fostered by employee Adhocracy perception, the felt opportunity for employees to participate in the decision making process, and the willingness of employees to share their knowledge. Knowledge sharing, in turn, is encouraged if teams are perceived as cooperative (rather than competitive) and if employees expect to be treated in a fair way (figure 7). It is again of special interest that individual and group perceptions are of higher influence than measurable environmental facts. The combination of employee participation, freedom of expression and high performance standards seems to be most suitable for creativity and innovation in the eyes of these authors.

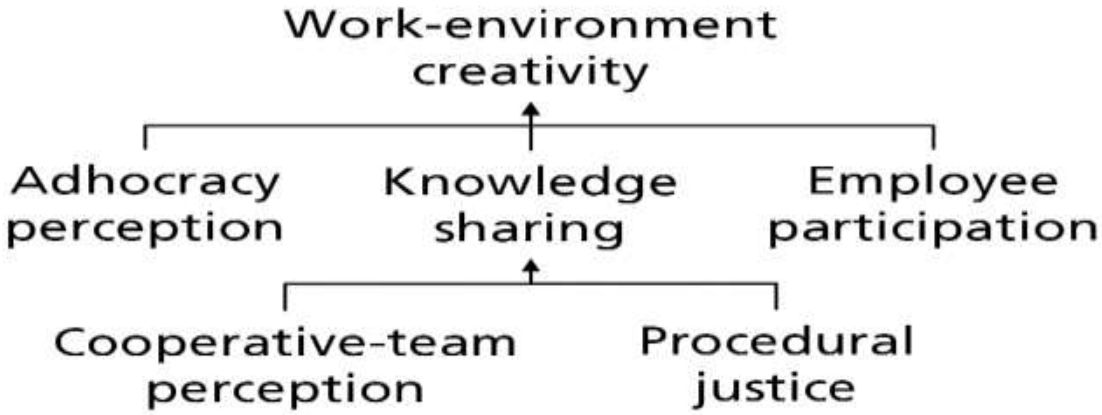

Figure 7: Factors conducive to work-environment creativity (adapted from Schepers & van den Berg (2007))

On the other hand, a feeling of personal insecurity is detrimental to the development of creativity. This feeling can be brought about by a seeming lack of support from the management (Wong 2003) and will be drastically intensified by precarious work contracts (Heinze 2007).

5.3. Resources

Heinze (2007) found that major creative events (in the sense of scientific breakthroughs) are more likely to occur in environments that provide some source of stable basic funding. He suggests that this reliability gives substantial freedom to think, especially about matters of no immediate utility. At the same time it reduces scientists' time spent on money-raising. The highly creative scientists he interviewed agreed that considerably more well-endowed multi-year awards should be granted to scientists, especially in the ascending stage of their career.Although the availability of resources is prerequisite for the effective performance of creative work, there is some evidence that over-abundance may lead to a loss in efficiency, mainly due to a loss of focus (Mumford 2000). In a similar manner, the introduction of a novel technology in itself might decrease creativity. This happens if employees are confused by the introduction of a new process, method or machine (Claver 1998). Knowledge is the main resource for producing knowledge. Access to relevant data-bases, literature and advanced computing facilities has been identified as a major requirement for creativity in the case of aeronautical engineering by Young (2007). But sophisticated computational tools can be double-edged swords: McMasters & Cummings (2002) caution against blind trust in simulation software as in many cases software engineers have included so many of their own biases and assumptions into the code that truly new ideas might well be determined as "beyond reality" if tested with software of this kind. Adequate buildings and working schedules can also be conducive to creativity. Some examples are: (i) Leaving spaces for informal discussion (e.g. large staircases and coffee rooms), (ii) spatial closeness between departments to foster interdisciplinary contacts, (iii) avoiding large offices with many employees that might create an atmosphere where informal discussion is discouraged. Common lunch breaks provide good opportunities of communication between employees of different organisational areas. Schedules that allow and encourage this will also help to support creativity (Heinze 2007).

6. CONCLUSIONS

Creativity research has contributed many practical guidelines on how to manage R&D in a way that fosters creativity. Most suggestions do not require the raising of major funds, but it is often small things that make a difference. It would certainly be desirable to create an ideal environment for creativity by combining as many positive factors as possible, but even the well-considered adjustments of a few parameters might have a considerable bearing on creativity. Most of the proposals compiled in this review will support each other in the actual process of enhancing creativity. Heinze (2007) has identified one particular set of contextual circumstances that, combined with the individual talents of scientists, is highly likely to lead to creative research: "Many of our highly creative researchers were recruited to these labs at an early stage in their careers, either as postdocs or junior staff researchers, and integrated into a mission oriented research program while giving them significant freedom to pursue the aspect of the overall program that they were most interested in or excited about. […] The context for this sort of work was characterized by organisations that provided significant job stability for its staff researchers, a base level of funding, […] and access to a large diversity of skills and interdisciplinary knowledge across the organisation. These research organisations were very well equipped with instruments and experimental capabilities that allowed the pursuit of empirical research in any direction the problem might suggest and the expert operators to yield reliable experimental results in a relatively short period of time. […] It was necessary to show a degree of research entrepreneurship within the larger directed context in order to focus on the problem of their interest and at the same time, the organisation provided the context and incentives for them to do so." What could be hindrances to remodelling an R&D department or an academic unit in the ways suggested? A major obstacle might be the fear of losing control by granting considerable freedom to small research units. This is a dilemma indeed: Control seems to be detrimental to creativity, but at the same time, some control of what is done in R&D is highly desirable for senior management. Two suggestions to overcome this problem have been made: First, to make the overall goal of the organisation very clear to every employee and second, to evaluate R&D regularly, keeping in mind that highly innovative thinking is risky and thus a "failure" might be a sign that a creative approach has been tried. The fact that it is not possible to plan the outcome of creativity might also lead to reluctance in investing money in highly innovative R&D. There are examples of companies that have been ruined by lack of return from costly but fruitless research activities, especially in the pharmaceutical sector. It is thus generally suggested to hold both low-risk product enhancement projects and high-risk innovation approaches in the research portfolio, a managerial practice easier to accomplish in large companies than in small business units. Joint ventures and consortium building might be methods for smaller organisations to share the burden of possible failure in highly innovative research.Finally it should be noted that to be efficient and effective, innovative action must be constant, as occasional or erratic efforts will probably not lead to any positive results (Claver 1998). It should have become clear in the course of this paper that creativity and innovation are not a matter of action plans and short-term campaigns, but have to be rooted in the very basic orientation of an organisation (Schepers 2007). As to R&D environments, there is hardly any doubt that scientific research on creativity is of considerable value. Unfortunately, only few studies have specifically been conducted on R&D so far, most notably the one by Heinze (2007). One issue raised in that study is reward. As the mechanism behind popular reward systems for scientists and engineers has been found to be contra-productive (section 3.1), novel systems that overcome these problems need to be devised and evaluated. Perhaps the introduction of friendly contest could be a valuable means in this context (section 3.3). Another issue that certainly wants closer examination is interdependence of motivation, reward and creativity. Basic research in this field will certainly help to improve the effective managerial running of R&D departments. Furthermore, the results of Heinze (2007) indicate that adequate buildings are beneficial for creative work (section 5.3). It would be useful to determine what kind of R&D working environment is most conducive for creativity and how these theoretical findings can be translated into practical building guidelines.The system that Cameron & Quinn (1999) have created to describe organisational culture appears to be a valuable theoretical foundation for further research on creativity in different industrial settings (section 5.1). It seems worthwhile to compare this theoretical framework with studies on corporate culture to fathom out correspondences and inconsistencies. Concerning theoretical considerations, there is a need to reconcile componential and sequential theories that exist side by side without having many joints to connect them. Some ideas on how they could be brought together have been outlined in section 2.3. This review shows that some valuable research on workplace creativity in R&D environments has already been conducted in recent years, but it also points out that a number of issues remain still unresolved. As effective R&D is considered a main driving force in modern economies, further studies should be carried out in this rewarding field of creativity research.

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