A Creativity Course for Engineers

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***Abstract* - This paper presents the principles of active learning and the contents of a creativity course entitled: Creativity and Problem Solving. The main purpose of this course is to create a space to discuss, reflect and experiment with creativity, creative processes and creative tools of relevance for students of any engineering speciality working with problem solving approaches. This course has run with big success since 1998 at the Technical University of Denmark. It started with very few students, now is a very popular course attracting many students from abroad. The selected themes, the methods and techniques, the structure of this course, the learning processes and the achieved results are presented. The results of students' and teacher's evaluations are also outlined. Finally some reflections, recommendations and conclusions are discussed.**

Index Terms – creativity, problem solving, learning processes, creative methods.

INTRODUCTION

The main purpose of this paper is to present our experiences from teaching a creativity course for engineers entitled: Creativity and Problem Solving. This course has been running since 1998. It begun with 8 Danish students and it has evolved to a very popular course. Last semester (Spring 2007), around 60 students applied to follow this course where there was only place for 30 students. It is important to mention that 75% of the students are coming from abroad. The course has evolved every year, and after five years it has taken its final shape, that is the one presented in this paper.

Our objective with this course is to create a space to discuss, reflect and experiment with creativity, creative processes and creative methods of relevance for engineering students of any speciality facing problems to be solved in an innovative way. We assume that this reflective, active and experimental approach will indirectly influence the development of the students own creativity.

This course has been grounded on learning experiences and praxes from three related areas: Action Learning, Action Research and Experiential Learning.

Action Learning [1] can be defined as a process in which a group of people come together more or less regularly to help each other to learn from their experiences.

Action Research [2] is a process by which change and understanding can be pursued at the one time. It is usually described as cyclic, with action and critical reflection taking place in turn.

Experiential Learning [3] is a process for drawing learning from experience. The experience can be something which is taking place, or more often is set up for the occasion by a trainer or facilitator. Clearly, both action research and action learning are about learning from experience. The experience is usually drawn from some task assumed by a person or a team.

All these learning experiences are cyclic. All involve action and reflection on that action. All have learning as one of their goals. Experiential learning functions by a dual alternation: between action and reflection; between unconscious and conscious principles. By engaging with both of these in a cyclic procedure, we integrate them. There are many methods and techniques that can support the team work at each stage.

Training of students creativity needs training concepts to be developed which tend to correspond to "freedom" rather than "order". Thus, it needs to deal not only with technical problem-solving, but also with more holistic creative processes, taking into consideration the most complex problems of reality today. These problems to be solved by the students have to be self-similar to such complex reality.

The paper covers four main sections. The next section will present shortly our interdisciplinary and holistic conceptualization of creativity and creative processes to be applied in problem solving. This interdisciplinary approach is one of the main principles of the course. The following section will present in detail the way how the course is carried out in practice. The different stages and corresponding learning styles of the course are described. Then, the third main section will present some evaluations of this teaching experience both from the student's and the teacher's viewpoints. The teacher's reflections about this teaching experience are outlined in the fourth section. Which competences did the students achieve? is a central question to be discussed. Finally, the last section presents the final remarks.

WHAT IS CREATIVITY?

Our main point of departure is the work of E. Paul Torrance [4]. He was a pioneer in creativity research and education for more than 50 years. Torrance asserted that creativity is an infinite phenomenon; you can be creative in an endless manner and that a central element in developing a person's creativity is practice.

You find creativity in many apparently different areas: humour (ha-ha), science (aha) and art (ah). Koestler [5] presents the theory that all creative activities - the conscious and unconscious processes underlying artistic originality, scientific discovery, and comic inspiration have a basic pattern in common, he calls it "*bisociative thinking*" - a concept he coined to distinguish the various routines of associative thinking from the creative jump which connects previously unconnected frames of references and makes us experience reality on several planes at once.

It is difficult to give a simple and general definition of creativity. It is easier if we restrain to study creativity in relation to problem solving tasks. Herrmann [6] gives a short definition that encapsulates many other definitions presented in the literature: *"What is creativity? Among other things, it is the ability to challenge assumptions, recognize patterns, see in new ways, make connections, take risks, and seize upon chance."*

The creative person. Maslow [7] distinguishes between "special talent creativeness" and "self-actualising creativeness" and he found that creativity is a universal characteristic of self-actualising people. Self-actualisation may be described as the full use and exploitation of talents, capacities, potentialities and the like. Such people seem to be fulfilling themselves and doing the best that they are capable of doing. He identified the following characteristics of self-actualising creativeness:

- Perception or fresh appreciation and wonder of the basic good of life,
- Expression or ability to express ideas and impulses spontaneously and without fear of ridicule from others,
- Childlike or innocence of perception and expressiveness, natural, spontaneous, simple, true, pure and uncritical,
- Affinity for the unknown,
- Resolution of dichotomies or the ability to synthesise, unify, integrate, and
- Peak experiences or fearless, wonderful, ecstatic experiences which change the person and his/her perception of life.

Their codes of ethics tend to be relatively autonomous and individual rather than conventional. They regard upon the world with wide, uncritical, undemanding, innocent eyes, simply noting and observing: what is the case? without either arguing the matter or demanding that it is otherwise. Self-actualising creativeness is "emitted", like radioactivity, and it hits all of life, regardless of the problems.

Miller [8] has developed a questionnaire that helps persons to identify their style of creativity. It is founded in three assumptions:

- Each person has the ability to think creatively in different ways, the main issue is: How is he or she creative?
- Each person has equal potential for creativity, but persons have different approaches to making change when they work, and
- There is not a single style, but a combination of styles, yet still each person has a favourite style.

A person's creativity style is founded in how he uses information to stimulate his creativity. Each creativity style prefers a different method for generating and evaluating ideas. Miller's research shows that preferences for style can be classified in four categories:

- *The modifying style* likes to ask: What can we adapt to improve upon what has worked before?
- *The visioning style* likes to ask: What can we realistically image as the ideal solution over the long term?
- *The experimenting style* likes to ask: What ideas can we combine and test?
- *The exploring style* likes to ask: What metaphors can we use to challenge our assumptions?

Amabile [9] has documented that creativity in each individual has three components:

- Expertise,
- Creative-thinking skills, and
- Motivation.

Expertise is in a few words knowledge in its many forms: technical, procedural and intellectual. Knowledge can be acquired both theoretically and practically. Learning to learn is an important tool for becoming an expert in modern Society. Creative-thinking skills determine how flexibly and imaginatively people approach problems and tasks. It demands courage to be creative because you will be changing the status quo. According to Amabile, individuals can learn to be more creative and can learn to use creative tools in problem solving. Motivation is the last component. An inner passion and desire to solve the problem at hand will lead to solutions far more creative than external rewards, such as money. This component, usually called intrinsic motivation, is the one that can most immediately be influenced by the work environment. Amabile's research has identified six general categories that support creativity: challenge, freedom, resources, work-group features, supervisory encouragement, and organisational support.

Amabile [10], after many years of research focusing on creativity within organisations has also concluded that individual creativity gets killed much more often that it gets supported. Mostly, it is not because management has a vendetta against creativity, it is undermined unintentionally because of the optimisation of short business imperatives: co-ordination, productivity, efficiency and control. Her research has shown that it is possible to develop organisations where both profit and creativity flourish, but you need a conscious strategy.

The creative process. Some conceptualizations of creativity are closely related to the process of sensing problems or gaps of information, forming ideas or

hypotheses, testing and modifying these assumptions and communicating the results. In this respect creativity is the ability to see a situation in many ways (*divergent thinking*) and continue to question until satisfaction is reached (*convergent thinking*). In creative work is a good idea to separate these two processes, first diverge then converge. The creative process can involve tiny creative leaps or giant breakthroughs. Both require that an individual or a group go beyond where they have gone before, embracing the unknown, the mysterious, the change, and the puzzling without fear.

Whether solving problems alone or in a group, you really must have a guided process i.e. a plan or a map of the steps to be followed. This is especially so in a group due to the need to align the capabilities of the members in a positive way. This map is usually called the creative problem solving process (CPSP) and under this denotation there exist a huge number of methods, tools and techniques to support the creative process during problem solving.

Group creativity has not been researched as much as individual creativity. Leonard and Swap [11] present their process for group creativity as five linear steps for discussion, while acknowledging that in practice it would look more like a "plate of spaghetti". The five steps are (1) preparation, (2) innovation opportunity (3) divergence: generating options (4) incubation and (5) convergence: selecting options. This process parallels creative problem solving techniques which involve cycling repeatedly through a process of divergent and convergent thinking: the diamond of the creative process.

HOW DOES THE COURSE RUN IN PRACTICE?

The course has been designed for a maximum of 30 students. From the beginning, each student will be member of a group that will work as a team during the whole course. Each group will usually be composed of 5 students. The course runs for 13 weeks. We meet one morning every week from 8 a.m. to 12 o'clock. Lectures always start at 9.00 am. The course schedule is divided in four parts.

First Part. This part runs for four weeks. It has been designed as a traditional course with seminal lectures and group exercises. The main purpose of the lectures is to give a holistic and multidisciplinary view of the field: Creativity and Problem Solving; focusing on theories, methods and applications. The bases for these lectures are three papers:

- *Creativity and Problem Solving* [12]: This paper presents some modern and interdisciplinary concepts about creativity and creative processes of special relevance for problem solvers and groups.
- *Creativity and Strategy Development* [13]: This paper focus on how creative thinking, processes and methods can support the strategy development and planning process in organisations.
- *The Vision Conference* [14]: This paper presents the principles behind the design and management of the Vision Conference: a one-day workshop in which a large group of participants meet to create ideas, projects and visions for the future activities of a local community or an organisation. The paper focuses on the three central social processes of the conference: group work, problem solving and facilitation.

The main goal of the group exercises is to form, prepare and develop the group to be able to work as a creative and purposeful team during the rest of the course. These four obligatory exercises are focusing on the following themes:

- Exercise where the groups are supposed to solve four creative puzzles.
- Exercise where the groups are supposed to solve a task in a creative way using two creative tools: brainstorming and mind mapping.
- Exercise where the groups work in a divergent manner suggesting proposals for possible projects using brainstorming to diverge. Finally, they will select from 3 to 5 projects for a final selection. These projects are usually related to the design of products, processes or organizations
- Exercise where the groups work in a convergent manner to find a final project. Two creative tools will be used for project evaluation.

Each exercise takes around 1 hour. The rest of the time, around 1 hour, the groups work with the creative methods that they have adopted. These methods will be presented in the second part of the course.

Second Part. This part runs for two weeks. In the first part of the course each group has already adopted a creative method. They have been studying and working with them and in this part all groups will give an oral presentation of their methods. The methods to be presented are:

- *Future Workshops:* The purpose of this method is to formulate innovative solutions and action proposals based on the participants' own experiences so that they can put these into practice. These proposals will usually be in relation to a local issue or challenge or in connection with the planning of local action concerning a particular development. See further [15]
- *Synectics:* This is an approach to creative thinking that depends on understanding together that which is apparently different. Its main tool is analogy or metaphor. See further [16].
- *Sociodrama:* Sociodrama is a way of simulating what happens in life in order to: explore social issues; develop greater understanding between groups and individuals; problem-solve and make decisions; experiment and try out new options; rehearse new roles and strategies and predict outcomes. Sociodrama is concerned with social learning in a group. See further [17].
- *Storytelling*: The purpose of this workshop is to use stories to build common understanding of a problem. When people participate in a common experience, many assume that there is shared

meaning about that experience. The participants will be invited to explore a situation from individual points-of-view with the intention of gathering collective information. Through personal stories a group story about a problem will be constructed. See further [18].

- *TRIZ:* TRIZ is a Russian acronym for "Teoriya Resheniya Izobretatelskikh Zadatch" a Theory of solving inventive problems or Theory of inventive problems solving (TIPS) developed by Genrich Altshuller and his colleagues since 1946. This is a methodology, tool set, knowledge base, and model-based technology for generating innovative ideas and solutions for problem solving. See further [19].
- *Morphological Analysis*: This is a method for exploring all the possible solutions to a multi-dimensional, non-quantified problem complex. In linguistics it refers to identification of a word stem from a full word form. As a problem-structuring and problem-solving technique, morphological analysis was designed for multi-dimensional, non-quantifiable problems where causal modelling and simulation do not function well or at all. See further [20].

These oral presentations should follow a delivered guideline and disposition. Creative presentations and performances are enhanced. The group presenting a method should plan a discussion of the advantages and disadvantages of a method where all the students should participate.

Third Part. The following 6 weeks the students will work in groups with a practical project selected by them in the first part of the course, approved and supported by the professor. Every Friday the professor will discuss with each group the different problems and tasks, the selection of methods, the design of the most suitable approach, etc. Some examples of projects are the following: Design of computerised systems, Design of a product or a process, Design of a new board game, Design of a firm that uses depleted tires as main raw material, Design of an organization for foreign students, Design of a new canteen at the University, Design of an action plan for an eventual landing of aliens, Design the school of tomorrow, etc.

The students will search for information, apply the creative methods and tools, interview relevant stakeholders, organise workshops, discuss in groups, use creative techniques, and they will be supervised to write a paper about their project. The students are encouraged to integrate the activities that belong to different parts of the human brain, logical as well as intuitive, factual as well as imaginative, quantitative as well as qualitative. The CPS approach will be the main guideline for the problem solving process.

The five steps of the CPS approach are:

1. *Fact finding:* Observe carefully and objectively, like a camera, while collecting information about the problematic situation
2. *Problem finding:* Clarify the challenge or problematic situation by considering different ways of regarding and reflect on those possibilities.
3. *Idea finding:* Look for more diverse ideas, alternatives, options, paths, ways, and approaches, use various methods and techniques (divergent thinking).
4. *Solution finding:* Examine ideas in new and different ways, from even more viewpoints and criteria; become aware of consequences, implications, and reactions to tentative idea/solution
5. *Acceptance finding:* Develop a plan of action, considering all audiences that must accept a plan. Seeks ways of making the idea/solution more workable, acceptable, stronger, more effective, and more beneficial.

At each step of the CPS approach some creative techniques could be used. For divergent thinking the most popular tool is *brainstorming*, while for convergent thinking *mind mapping* is widely used.

Each group will report the achieved results in the form of a scientific paper to be published in an international journal. All groups will be advised on the art of writing creative papers.

Fourth part. Finally the course ends with a conference where all groups will present their projects in an engaged and participative way. The schedule of the day is organised as an international conference. After the presentation of each group the students will discuss the used approach and will suggest alternative methods and problem solving processes.

EVALUATIONS

At the very first day the students will be presented with the purpose of the course and the program to be followed. The students might suggest changes and modifications. Then, groups will be formed. Some few students (from 3-4) will drop out of the course already this same day or they will not show up the next week. Usually students will book for more courses that they can cope in a semester and the very first week they make a final decision about which courses they will follow the semester.

At the Campus net of the University the students can evaluate the course replying to a standard evaluation scheme. Around 65% of the students will reply to this evaluation. Those students not replying are usually foreigners that are only coming for a semester. Summarizing, the students in these replies express a high satisfaction with the course.

For most students this course is the first time that they will confront with the principles of Active Learning. Most of them have been from 3 to 4 years at the University. The students are overwhelmed about the possibility of taking responsibility for their own learning in team work. This course is not a burden; students are highly motivated and

happy to participate in all the activities in a creative, cooperative and collaborative way.

The students also praise the engagement, wisdom, enthusiasm, and charisma of the teacher. At the beginning of the course the teacher will use a hierarchical teaching style as a traditional teacher. In the second part the groups will takeover the lecturing activities and the teacher will be an adviser to the groups. Finally, at the last part of the course the teacher will function as a supervisor for each group.

Seen from the teacher's chair, the objective of the course has been fully fulfilled. This will be reflected in the marks obtained by the students. These are normally distributed from more than satisfactory to excellent.

In this course all the students have experienced to:

- Work in groups,
- Have some fun,
- Feel free enough to be creative (learn to fly!),
- Practise their communication skills,
- Practise some creative methodology,
- Practise some facilitation skills,
- Deal with real-life problems, and
- Learn from other groups

All the students obtain a grounded basis in creative tools and methods that can be used in their future work with other courses, work with their final thesis, and for their future professional life. Some students will be highly motivated to continue working with the teacher towards the design of a project that can be the subject for a Master Thesis. Some of these projects have been: The establishment of a consulting firm selling creativity, Strategy development for a consulting firm, Creativity tools for small firms, and the application of a multi-methodological approach to software design for optimization. All these students, after finishing their theses, have continued working with creativity either establishing their own firms or getting jobs in consulting firms where it is expected to work with innovative projects.

REFLECTIONS

Many students find the demands of a creative role both unfamiliar based in the principles of action learning and uncomfortable and it is therefore important that they learn methods that will help them to develop a creative attitude to problem solving work. They need to be able to recognize when a creative approach is required and to be able to engage in a creative mode. In order to do this they need to have an appropriate toolkit which will enable selection of the right tool for the task in hand. The informing part of these needs can be fulfilled through traditional teaching methods, but in order to gain experience it is essential that projects are used. It has long been recognized that projects are the best methods for achieving this and developing recognition of creative ability, which is vital to the overall education of problem solvers.

One essential element in this course is what has been called collaborative learning. This means that students learn best when they are actively involved in the learning process and that they learn best when they work in small groups. They will be motivated for learning when parallel with the subject to be learned, they learn to learn in a study team. Study teams are long term groups existing over the course of a semester with stable membership whose primariy responsibility is to provide members with support, encouragement, and assistance in completing course requirements and assignments when someone has missed a session. Collaborative learning is an effective way to deal with complex problems and at the same time to learn to learn in practice.

Another theme of interest is that our course is based on what is known as Project-Based Learning [4]. The students are grouped in teams; learn to work together in a project oriented way following the above-mentioned cycle in a non-structured manner. They learn via contextualized problem situations. Because of that, and all that goes with that, namely the dynamics of group work and independent investigation, they achieve higher levels of comprehension, develop more learning and knowledge-forming skills and more social skills as well.

My reflections about my teachings are usually supported by the Critical Theory of Habermas [21]. Habermas differentiates three primary generic cognitive areas in which human interest generates knowledge. These areas determine categories relevant to what we interpret as knowledge. That is, they are termed *knowledge constitutive* - they determine the mode of discovering knowledge and whether knowledge claims can be warranted. These areas define cognitive interests or learning domains, and are grounded in three different aspects of social existence - work, interaction and power. Work Knowledge broadly refers to the way one controls and manipulates one's environment. This is commonly known as *instrumental action* - knowledge is based upon empirical investigation and governed by technical rules. The criterion of effective control of reality direct what is or is not appropriate action. The empirical-analytic sciences using hypothetical-deductive theories characterize this domain. Much of what we consider 'scientific' research domains - e.g. Physics, Chemistry and Biology and methods for problem solving are classified by Habermas as belonging to the domain of Work Knowledge.

The Practical domain identifies human social interaction or *communicative action*. Social knowledge is governed by binding consensual norms, which define reciprocal expectations about behaviour between individuals. Social norms can be related to empirical or analytical propositions, but their validity is grounded only in the intersubjectivity of the mutual understanding of intentions. The criterion of clarification of conditions for communication and intersubjectivity (the understanding of meaning rather than causality) is used to determine what appropriate action is. Much of the historical-hermeneutic disciplines - social sciences, history, aesthetics, legal, ethnographic, literary and

so forth are classified by Habermas as belonging to the domain of the Practical Knowledge.

The Emancipatory domain identifies *self-knowledge* or self-reflection. This involves interest in the way one's history and biography has expressed itself in the way one sees oneself, one's roles and social expectations. Emancipation is from libidinal, institutional or environmental forces which limit our options and rational control over our lives but have been taken for granted as beyond human control. Insights gained through critical self-awareness are emancipatory in the sense that at least one can recognize the correct reasons for his or her problems. Knowledge is gained by self-emancipation through reflection leading to a transformed consciousness or *perspective transformation.*

Now we can ask the following question: What are the competences achieved by the students of this course? The concept of competence consists of three dimensions: The know-what, the know-how and the know-why. It is inspired by Habermas' type of knowledge: instrumental knowledge, practical knowledge and emancipatory knowledge [22]. Know-why when evaluating students has been described as potentially painful for the learner as he/she will have his/her conception of the world disturbed and though it is not the goal, emancipatory learning probably occurs. Learning to learn and creativity as a way to get liberated from routines can have some emancipating aspects. The two first dimensions are of relevance for our purpose. The know-what and the know-how are the most important types of knowledge for the problem solving students. It is necessary really to understand both know-what and know-how to achieved satisfying work in creative problem solving. All students achieve this competence in the course.

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FINAL REMARKS

It demands courage to run such a course in a competitive academic environment where students have most often been rewarded for individual effort; collaboration may not come naturally or easily for everyone. The success of this experience is very much conditioned by student's participation and motivation. You cannot force students to be more creative in a collaborative way but at least you can make them reflect about the importance of creativity. It is my experience that students learn best when they are actively involved in the learning processes. The rewards for the teacher are many: developing experiences in creative learning, getting in contact with creative students, enjoying the work as a creative supervisor, etc. But it is hard work; you have to be open to new ideas and willing to learn all the time.

The teacher has to be:

- Generous, given knowledge as presents,
- Supportative, supporting that each group seeks for excellence in its work,
- Reflective, about the evolution of each student and the groups,
- Creative, suggesting new ways to solve problems,
- Emphatic, feeling the best way to learn for each student and groups, and
- "Radioactive", emitting all the time a good atmosphere for work.

Our experiences have shown that it is possible to design a course for students with the purpose to teach creative thinking, creative problem solving and creative methods using a project-based learning process. Within this context learning to learn is a creative problem solving itself. In this way learning gets very close to reality, in the sense that the learning situations are quite similar to one problem solvers experience in their jobs as consultants, experts or facilitators.

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