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TEACHING ENGINEERING STUDENTS CREATIVITY: A REVIEW OF APPLIED STRATEGIES

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Abstract

Recent studies have emphasized the necessity of educating creative engineers. This paper aims to provide a literature review by answering what strategies can be applied to develop creativity in engineering education. As the literature demonstrates, creativity has been studied by a diversity of perspectives such as psychology, social psychology and sociology. Studies on engineering creativity indicate the importance of problem-solving skills for engineers. For developing creativity, strategies such as using thinking tools, learning by solving problems and building learning environment conductive to creativity have been suggested in engineering education. Problem-Based Learning (PBL) is a strategy of developing creativity. So characteristics of PBL, learning cycle in PBL and methods for enhancing group dynamics in PBL are discussed in this paper. In addition, Aalborg University in Denmark is introduced as an example of PBL strategy.

Key Words

Creativity, engineering education, Problem-Based Learning (PBL), strategy

Introduction

Creativity is widely acknowledged as vital to engineers. Success of engineers in their profession depends radically on the level and amount of creativity and innovation they exhibit in developing sustainable engineering concepts, components and systems, engineering design and their implementation (Panthalookkaran, 2010). However, to many engineers, creativity is nebulous concept that rests uneasily in the precise quantitative engineering world. Creativity is thought as a subject that cannot be taught; it is almost like a talent of an individual that one possesses or not as the case may be (Thompson and Lordan, 1999). This indicates some efforts are needed from educators who play important roles on making young engineers understanding and mastering creativity more explicitly.

This calls for strategies of developing engineering creativity. However, the literature shows creativity has been studied by diverse perspectives and given a wide range of definition. As discussed by Liu and Schoenwetter (2004), defining creativity is a daunting task, because there are very many published definition of creativity ranging from the very simple to highly complex(Thompson and Lordan, 1999). This brings difficulties to educators in designing or employing strategies of developing creativity. Furthermore, studies on engineering creativity indicate the importance of providing students problem-solving contexts in engineering curriculum. Therefore, this paper aims to review published studies by answering what strategies can be applied to develop creativity in engineering education. The review contributes to an outline of how to teach engineering students creativity and understanding Problem-Based Learning (PBL) as a good example of fostering creative engineers.

Studies of Creativity

Definition and Perspectives of Creativity

Generally, creativity is defined as a judgment of the novelty and usefulness (or value) of something (Amabile, 1996). However, there is a great deal of controversy about the meaning of the word creativity, particularly in a university setting (Toernkvist, 1998). Is creativity a mysterious gift? a unique talent? a trait? an attitude? Is it innate, or can it be learned and taught (Richards, 1998)? According to Sawyer (2006), creativity is not the myth. Creative potential exists among all people. Through deliberate intervention, in the form of training or instruction, individuals can make better use of creativity, enhance their level of creative accomplishment, and thus realize more fully their creative potentials (Treffinger, 1995).

The curiosity of creativity also drives to deepen and broaden the meaning of creativity. For example, Klein and Shragai (2001) suggest creativity is many things; it is a way of looking at the world and a way of opening up avenues to opportunity, adventure, and self-confidence. Meanwhile, diverse perspectives of studying creativity have been explored during the past years. As pointed out by Toernkvist (1998), the literature is enormous and spans a number of disciplines:

1. Psychology has focused on the individual's creativity and tried to identify the cognitive capacities and/or traits of personality that make up a creative person.
2. Social psychology has studied the process of creativity as an interaction within a given context.

3. Sociology (and organization theory) has emphasized creativity as an environmental process and studied efficient communication networks made up of prominent personalities with broad and deep knowledge.

Based on these main perspectives, a multi-level approach to study creativity has been asserted by considering at least three levels of analysis (Borghini, 2005): 1) intrasubjective (individual), 2) intersubjective (group), and 3) collective (organization). This approach helps to understand how in the creative process, individuals (in the context of groups and organizations) contributes to the outcome of a creative product through a sensemaking process. In other words, creativity is not only individual cognitive, but also collaborative or social.

Creativity in Engineering

According to Cropley and Cropley (2000), the nature and role of creativity and innovation has received only modest attention over a long period of time, in engineering education literature. However, more recently, the need for people skilled in helping others use creative problem solving is increasing. This need is evident in both engineering and the practice of pedagogy. As pointed out by Charyton and Merrill (2009), creativity has received greater necessity, rather than an accessory in engineering design.

Accordingly, meaning of engineering creativity has been discussed. For example, Gregory and Monk (1972) suggested that engineering creativity is demonstrated in the satisfaction of human needs by the exploitation of matter or energy or other material resources in a more effective manner. This means that for engineering, there is a tension between the need to produce novelty and the necessity of effectiveness, with the latter likely to be emphasized at the cost of the former (Hoffmann at el, 2005). Cropley and Cropley (2005) refer to creativity possessing this particular property as functional creativity, which means that products designed by engineers typically serve a functional and useful purpose, unlike fine art. The purpose is to create useful products (to perform tasks or to solve problems) (Charyton and Merrill, 2009). As Burghardt (1995) suggests, technology is the manifestation of engineering creativity. The products of engineering creativity are physical objects, complex systems such as a submarine or a business information system, or processes in the sense of a service, technique or method (a manufacturing process, a control process, a logistic service) (Hoffmann et al, 2005).

This is not to say that non-engineering creativity is devoid of purpose. As suggested by Hoffmann et al (2005), creativity in general is essential for progress and growth, which in itself is enough to give all creative efforts purpose. In contrast to "general creativity"—creativity that is not domain specific, the emphasis of engineering creativity is more on capability of problem solving. Engineers not only need to address aesthetics like artists, but also need to solve problems, prevent potential problems, and address utility within the constraints and parameters that are designated (Charyton and Merrill, 2009).

Strategies of Developing Creativity in Engineering Education

According to literature, creativity is an ability that students can achieve by using effective exercises and through a suitable environment (Adams et al, 2008). Furthermore, problems could be the sources of creativity that has been emphasized on teaching creativity to engineers (Liu and Schoenwetter, 2004). Accordingly, as the literature indicates, the strategies of fostering creative engineers explored have been mainly followed three lines: 1) using thinking tools, 2) building learning environment conductive to creativity, and 3) learning by problem-solving.

Using Thinking Tools

As suggested by Liu and Schoenwetter (2004), instructor begins with direct instruction in using thinking tools, and then incorporates the tools into course contents. Note that students need know how to use the tools specifically and effectively, in order to facilitate the idea generation. The literature shows there are very many publications concerned with creativity thinking tools. For example, in the early 1980s, Geschka (1986) identified 50 and expanded on 23 creativity and ideas generation tools. However, according to Thompson and Lordan (1999), many are variations of core tools and therefore stem from the same basic principles. Here, a review is given of the tools that are most relevance to engineers (Liu and Schoenwetter, 2004; Thompson and Lordan, 1999). The tools include:

- Analogical thinking
- Brainstorming
- Idea checklists
- Mind mapping
- Morphological analysis

Analogical thinking: Researchers in cognitive psychology generally agree that creativity consists of reassembling elements from existing knowledge bases in a novel fashion to produce a new idea. Analogical thinking has been proposed as a basic mechanism underlying creative tasks, in which people transfer information from existing categories (i.e., base domains) and use it in the construction of their new idea (i.e., the target domain) (Dahl and Moreau, 2002). By the use of analogies, an individual or group can often find a new insight and approach to the nature of a problem (Thompson and Lordan, 1999). To implement this technique, students are encouraged to deliberately ask questions like 'What else is like this?' 'What have other done?' 'Where can I find an idea?' and 'What ideas can I modify to fit my problem?'

Brainstorming: As the most frequently used tool to generate new ideas, brainstorming means bouncing ideas out about a subject, no matter how wild or ridiculous they may appear like (Liu and Schoenwetter, 2004). It made a breakthrough in applying the psychology of creativity to the problem-solving activities of the real world and has been recommended as probably being of best use in some combination of individual and group practice (Paulus, 2003). Four basic rules of brainstorming were given: (1) Criticism is ruled out (to uphold the principles of deferred judgment); (2) Freewheeling is welcomed (variety of ideas to stimulate originality); (3) Quantity is wanted (quantity leads to quality); and (4) Combinations and improvements are sought (listen to others' ideas and improve by additional insights or combination of ideas) (Osborn, 1953).

Idea checklists: The thinking tool of idea checklist means making a checklist that will encourage the user to examine various points, areas, and design possibilities of a subject (Liu and Schoenwetter, 2004). It is used extensively in engineering design as a means of evaluation. There are different kinds of check-lists mentioned in literature (Thompson and Lordan, 1999), for example, Osborn proposed a list of nine questions including "magnify?", "modify?", "rearrange?" and "reverse?" etc (Osborn, 1953). Gregory (1979) listed his questions under functional headings: economic, understanding, practice, technological stretching, cross-fertilization, guessing the trend, and new axes of reference. The manipulative verb check-list may provide words for identifying possible insights or alternative approaches to solving a problem. The list also helps to generate ideas by taking a verb from the list and "checking" the verb against certain aspects of the problem, e.g. how to implement a proposal (Liu Schoenwetter, 2004).

Mind mapping: Whereas brainstorming and checklist are ways to generate ideas; mind mapping serves as a tool for structuring ideas. It was firstly developed by Tony Buzan (1976), a mathematician, psychologist and brain researcher, as a special technique for taking notes as briefly as possible whilst being interesting to the eye. Now it has been turned out to be usable in many different ways other than just simple note taking (Brinkmann, 2003). Mind maps are hierarchically structured and produced. On a large sheet of paper the topic of the mind map is placed in the center and from this point of departure main ideas is linked by drawing branches, which again can be linked with sub-branches to elaborate on the idea (Mento, Martinelli and Jones, 1999). This kind of visual representation of ideas creates an overview of related ideas and helps one to think about a subject in a global, holistic sense and increases mental flexibility.

Morphological analysis: Morphological analysis is well known in engineering design. A problem is divided into functions, or even further subfunctions, that must be performed and alternative ideas generated for each function (or subfunction). Therefore, there are very many possible solutions to the problem created from the number of permutations of the solutions to each function. The difficulty for the designer is to choose the best solution from the large number of option available and, in practice, searches are quickly abandoned once a few acceptable solutions are found (Liu and Schoenwetter, 2004; Jones, 1970).

The above tools reviewed are some examples that facilitator can use in engineering classrooms. Furthermore, some other tools are often mentioned in literature, such as wishful thinking, brainwriting (Thompson and Lordan, 1999), and TRIZ (Baille, 2006). These tools can open up more channels for students to highly-efficient divergent thinking and thus help students to engage in the initial stages of the creative process (Liu and Schoenwetter, 2004). However, according to Baillie (2006), there are no rules to creative thinking—however, the skill of the facilitator is to create the atmosphere that is conductive to idea generation, as well as selecting the most appropriate technique, for the participants, in their context and with their particular problems to solve.

Building learning environment conductive to creativity

The social approaches to creativity have emphasized the shaping roles of environment on creativity (Amabile, 1996; Toernkvist, 1998). The development of creativity is affected by both personal and situational factors (Liu and Schoenwetter, 2004). As suggested by Plucker et al (2004), creativity is the interaction among aptitude, process, and environment by which an individual or group produces a perceptible product that is both novel and useful as defined within a social context. So Mitchell (1998) emphasize that teaching creativity in engineering education means to create a cooperative and safe learning environment so that student share ideas, form theories, explore concepts and work collaboratively in teams.

Accordingly, Kazerounian and Foley (2007) propose a list of ten factors that is called the Maxims of Creativity in Education that constitute an educational environment conductive to fostering creativity in engineering students. The Maxims are: 1) keep an open mind; 2) ambiguity is good; 3) iterative process that includes idea incubation; 4) reward for creativity; 5) lead by example; 6) learning to fail; 7) encouraging risk; 8) search for multiple answers; 9) internal motivation; and 10) ownership of learning. Similarly, Richards (1998) suggests strategies such as 1) don't be afraid to be different, 2) be open and receptive to new ideas, 3) relax, 4) reflect, and 5) have fun, etc.

Furthermore, Liu and Schoenwetter (2004) emphasize it is the facilitator's responsibility to teach students how to recognize and remove blocks to creativity. As suggested by Kazerounian and Foley (2007), when teachers manipulate the learning environment such that students felt it is more accepting of risky behavior, students' creativity increased. Therefore, Liu and Schoenwetter (2004) summarize some common blocks and solutions of removing the blocks (Table 1).

	Blocks to Creativity	Solutions of Removing Blocks
Fear of the unknown:	Avoiding unclear situations; overweighing the unknown versus the known; and needing to know the future before going forward.	Teaching students efficient means of information gathering skills to clarify the situation.
Fear of failure:	Drawing back; not taking risks; and settling for less in order to avoid possible pain or shame of failing.	To provide students with opportunities of failure with the intent of using these opportunities as teachable moments—times when students are usually most receptive to an explanation of why it did not work.
Reluctance to exert influence:	Fearing of using aggressive or push behavior which may influence others; hesitating to stand up for what one believes; and failing to make oneself heard.	Incorporating stories of inventors who, because of their persistent belief in their innovations, even when faced with opposition provided valuable products.
Frustration avoidance:	Giving up too soon when faced with obstacles, in order to avoid the pain or discomfort that is often associated with change or novel solutions to problems.	Telling stories about great inventors, such as Edison who survived thousands of experimental failures.
Resource myopia:	Failing to see one's own strengths; and depreciating theimportance of resources (i.e. people and things) in one's environment.	Role-modeling integration of personal strengths with the resources available.
Custom-bound:	Over-emphasizing traditional approaches or methods; and strongly revering for the past; and tending to conform even when unnecessary.	Providing students with opportunities to brainstorm new ideas based on classic traditions.
Reluctance to play:	Not playing around with material; fearing of seemingly foolish or silly act by experimenting with unusual.	Providing students with 'hands-on' learning experiences, making theories tangible.

Reluctance to let go:	Trying too hard to push through solutions to problems, instead of letting things happen naturally; and distrusting of human capacities.	Providing students opportunities to make things as they with and encouraging them to go ahead.
Impoverished emotional life:	Depreciating the motivational power of emotion; attempting to hold back spontaneous expressions; and neglecting the importance of feelings in achieving commitments.	To provide opportunities of celebrating student achievements. Some engineering schools achieve this through various national and international competitions, rewarding the creative efforts of students.
Over-certainty:	Persisting in non-functional behavior; and failing to check out one's assumptions.	Providing students with opportunities to reflect and evaluate their methods of creative problem solving.

Table1: Blocks to creativity and strategies of removing blocks

Learning by Problem-Solving

Since engineering creativity is characterized as functional creativity, and it emanates from engineering problems, it seems more natural for engineering students to gain creativity through practice of problem-solving (Liu and Schoenwetter, 2004; Cropley and Cropley, 2005). As emphasized by Tan, Teo and Chye (2009), problems are sources of creativity. Problem solving is a process in which the learner selects and uses rules to find a solution in novel way (Treffinger, 1995).

Furthermore, cognitive science and cognitive learning theories play an important role in our understanding of the mechanism of problem solving and the application of creativity in humans (Adam et al, 2008). A problem triggers engagement in terms of emotional motivation and deep thinking. When we are solving a problem, we engage in an active search for meaningful information, a proactive immersion in the task, a conscious and subconscious investment of time on the task, and a search for meaning and explanation, along with the adoption of goal and future orientations (Figure 1) (Tan et al, 2009).

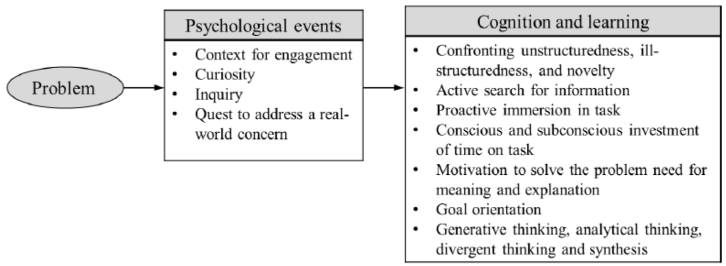

Figure1: Problems lead to cognition and learning

Accordingly, Creative Problem Solving (CPS) approach has been discussed much in literature (Baille, 2006). According to Treffinger (1995), the current CPS framework include three major components (Understanding the problem, Generating ideas, and Planning for Action) and six specific stages (Mess-Finding, Data-Finding, Problem-Finding, and Acceptance-Finding). This framework calls on individuals and groups to invest a substantial degree of thought or reflection, imagination, judgment, and energy in their creative problem solving efforts. Bransford and Stein (1993) suggest an IEDAL cycle for solving problems and they encourage entering this cycle at any point and recycling through the steps as needed. The following steps of the cycle are: 1) Identify problems and opportunities, 2) Define alternative goals, 3) Explore possible strategies, 4) Anticipate and act, and 5) Look and learn. Adams et al (2008) point out a five stage process of teaching problem solving based on work of

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Woods (1977) and Polya (1957): 1) Define the problem, 2) Think about it, 3) Plan, 4) Carry out the plan, and 5) Look back.

Moreover, Liu and Schoenwetter (2004) suggest case studies, simulations, role playing or team work in teaching problem solving. They discuss a model made by Treffinger et al (2000), which consists of three hierarchical levels: learning and using basic thinking tools; learning and practicing a systematic process of problem solving; and working with real problems. The use of thinking tools provides a structural methodology for their applications in solving problems. In addition, as a good example of teaching engineering creativity, Problem-Based Learning (PBL) has been discussed much in literature (Awang and Ramly, 2008; Adams and Turner, 2008; Fruchter, 2001), as introduced in the following.

Problem-Based Learning (PBL): A Strategy of Fostering Creative Engineers

PBL and Methods for Creativity in Student Groups

Through learner-centered and constructivist, Problem-Based Learning (PBL) offers a framework for structuring and facilitating learning and group processes based on creative problem solving. The literature demonstrates PBL has been employed in different areas of higher education such as business management (Smith, 2008), medicine (Hendry et al, 2003), and engineering (De Graaff and Kolmos, 2007). In engineering education, PBL has become increasingly accepted due to its principles of integrating knowledge across disciplines and developing expected professional competencies among students by bridging university and society (De Graaff and Kolmos, 2007).

In PBL, student learning centers on a complex problem that does not have a single correct answer. Students work in collaborative groups to identify what they need to learn in order to solve a problem. They engage in self-directed learning and then apply their new knowledge to the problem and reflect on what they learned and the effectiveness of the strategies employed. The teacher acts to facilitate to the learning process rather than to provide knowledge (Hmelo-Silver, 2004). As suggested by Savin-Baden (2000), PBL can offer staff and students the opportunity of learning to 'make sense' for themselves, personally, pedagogically and interactionally. It can also help to realize the value and complexity of it as an approach to learning and the ways in which it can help students to understand and challenge their situations and frameworks by encouraging them to learn with complexity and through ambiguity. Accordingly, PBL scenarios are characterized by the following features (Porath and Jordan, 2009):

- Ill-structured problems. The nature of real-world problem is that they are often without the types of boundaries or structures that define problem solutions. Most problems, in reality, are confounded with other variables and need to be teased out of social, emotional, cultural, and environmental contexts.
- Partial information. When we encounter problem in real life, we often have only partial information available to us at first when we try to find a solution. At times, additional information is found or presented to us during the solution process.
- Questions that belong to students. PBL scenarios are designed to give students the opportunity to become self-directed in their search for solutions, thereby making

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them, rather than the teacher, the persons who develop the questions.

- A real problem with a number of plausible solutions. The ill-structured nature of real problems means that often there is more than one solution. There may be a right answer, but it is also possible that the right answer is mixed in with a number of plausible answers and so further investigation would be required.
- Requirement of cooperative group work. The reality of most problem-solving situations in life is that they are group efforts. We tend to seek out individuals who have information that could be useful to problem solution and usually discuss our findings to solidify our understanding of problems and situations. This natural collaborative problem-solving tendency is captured in the PBL procedure.

The student learning process in PBL may be structured in different ways. One of the most well-known models is the seven-jump method (Segers et al, 2003). Poikela et al (2009) provide a model of PBL learning cycle that also demonstrates tutorial process (Figure 2). In this cycle, the PBL process begins with students working toward a shared understanding of the problem presented to them. They then brainstorm ideas about the content area related to the problem using their existing knowledge and prior experiences. Similar types of ideas are grouped into named categories. The most important and actual problem areas among the named categories are determined. The first tutorial session is then held to decide on the learning tasks to undertake and the goals to achieve. Following the tutorial, students engage in information search and self-study, working both individually and in pairs or in small groups depending on the learning tasks and goals as well as the strategy deemed most appropriate for seeking information. The second tutorial is the time for applying the new knowledge acquired, to tackle the learning tasks, and to reconstruct the problem in a new way. New and deeper knowledge is synthesized and integrated to provide a basis for deeper learning. Participants clarify and reflect on the whole problem-solving process in the light of the new knowledge. Assessment is part of every single phase of the process. It is necessary to close the tutorial with feedback about students' own learning, their information-seeking behavior, their problem-solving skills, and the group processes so that improvements can be made (Poikela et al, 2009).

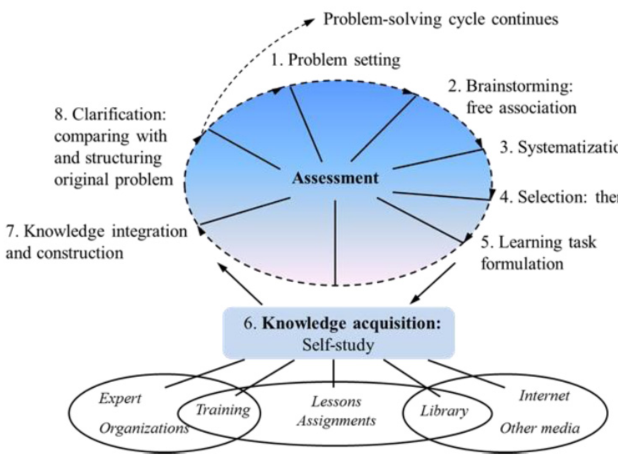

Figure2: Problem-Based Learning cycle

Therefore, the tutor coaches the group by monitoring the group process and helping the students to identify the knowledge that is needed to resolve the problem (Poikela et al, 2009). So "student-centered learning" is the core philosophy of PBL (Dolmans, 2001; Zhang, 2002). The tutors are expert leaners, able to model good strategies for learning and thinking, rather than experts in the content itself. They are responsible both for moving the students through the various stages of PBL and for monitoring the group process. This monitoring assures that all students are involved and encourages them both to externalize their own thinking and to comment each other's thinking (Hmelo-Silver, 2004). Accordingly, methods for successful collaboration and inspiring creativity in PBL environment have been specially suggested (Gerhardt and Gerhardt, 2009), such as:

- Six Hats Method by Edward de Bono. This technique can enhance diversity of thought by applying different types of thinking to the subject. It can fostering creativity by maintaining a playful (not too critical) attitude as everyone in the group switches from one metaphorical "hat" to another, each representing a different mindset. The six hats comprise the following: White hat is cold, neutral, and objective; while wearing it, you can look at the facts and figures. Red hat represents anger (seeing red), and it signals the times to listen to your intuition and emotions. Black is careful and cautious. Yellow is sunny and positive. Green is full of creative new ideas. Blue is the organizer of thoughts.
- Changing the Environment. By moving outdoors or to a more or less stimulating environment, team productivity may be enhanced or the focus refreshed. Rearranging the furniture in the team meeting room can give the team a fresh perspective. Change the environment and maybe the idea previously set will change as well. It can be very helpful to be in the environment or setting for which one is designing or about which one is learning.
- Handing around Partial Solutions. Try handing around incomplete concepts to get unexpected ideas. The idea behind this is that even if one group member cannot complete the entire cycle, someone else in the group may be able to. This principle is very powerful in collaborative efforts, such as where group work on research publications or even where students work on collaborative papers. The work is completed relay style, passing the baton from runner to runner, and in this way optimal effort can be maintained.

Furthermore, techniques for enhancing group productivity have also been suggested to use in PBL student group meetings (Gerhardt and Gerhardt, 2009). For example, in the first group meeting, the following group-building and meeting-management techniques can be employed:

1. *Introductions* to help group members know each other
2. *Establishment of the agenda*, to which all group members can contribute
3. *Check in/check out*, an exercise held at the beginning and end of the meeting in which group members assess how they feel about the progress of the group and their own expectations
4. *Establishment of group norms*, a discussion of important guidelines and group rules including:

   a) The obligation to dissent, which is the obligation of group members to voice their opinions and concerns even when it means disagreeing with other group members

   b) Use of a peer leadership model, where different "emerging" leaders take turns to lead different phases of the project at hand

c) Use of the standard agenda creation process to ensure that group members know what will be discussed during the group meeting

d) Use of the check-in/check-out process at each meeting to keep the group apprised of individual concerns.

5. Establishment of group meeting schedule for regular meetings, for example, each week during the lunch hour on Tuesday and Thursday.

As mentioned previously, to foster flexible thinking, problems need to be complex, ill-structured, and open-ended; to support intrinsic motivation, they must also be realistic and resonate with the students' experiences (Hmelo-Silver, 2004). So Project-Based Learning has also been applied to engineering education (De Graaff and Kolmos, 2007). According to Steiner and Blicblau (1998), the projects relate basic principles and concepts to real problems and they promote understanding of basic concepts, enabling deep learning, broadening knowledge and encouraging creativity. They stimulate an enjoyable realistic exercise, encompassing time and financial restraints, while learning to perform duties as part of a professional team. However, some researchers point out Project-Based Learning is different from Problem-Based Learning. For example, Savin-Baden (2007) argued that project-based learning is more often seen as a teaching technique in a given area of the curriculum rather than an overall educational strategy such as problem-based learning. However, both Problem-Based Learning and Project-Based Learning would be seen to be synonymous because both are perceive to be student-centered approaches to learning.

Aalborg University in Denmark: An Example of PBL Environment

Aalborg University (AAU) in Denmark has a long tradition for PBL since 1974. The project work model is used in all levels of education at AAU. The traditional Aalborg model is founded on problem-based project work, in which approximately one half of the students' time is spent on project work in teams, whereas the other half is spent on more or less traditional lectures. All project work is made in groups, and the same model is followed from 1st semester until the completion of a masters' degree (10th semester). During the span of the university degree programme, the groups normally become smaller, starting with typically 6-7 students in the 1st year, and reduced to maximum 2-3 students in the final semester (Kolmos et al, 2004).

In each semester, the project and the majority of the courses must relate to the theme of the actual semester. The students are supposed to attend the courses and apply them in their project work, and the output of the courses is assessed along with the project report at the end of the semester. The examination is a joint group examination with individual marks and takes up to six hours. The work with the project report and courses—the theme—covers approximately 80% of the semester, equivalent 24 ECTS (European Credit Transfer System). A full semester is 30 ECTS points. The rest of the semester includes fundamental courses or other compulsory course (study courses) assessed by more traditional examinations (Figure 3) (Kolmos et al, 2004).

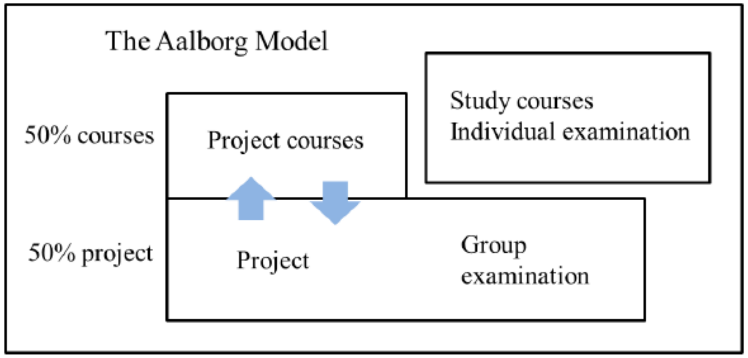

Figure3: The traditional Aalborg PBL model

To ensure a certain education, the project must fulfill some educational demands based on themes for the individual semesters. The specific problems, the groups work with in their project, can either be suggested by themselves, but most likely it is suggested by a scientific staff member, often in co-operation with industry. The students carry out the projects all the way from problem formulation and analysis, through the problem solving, and to the final result which is often an 80-200 pages report and for the engineer students, and most often also a prototype of the (sub-)system they have been working on as well as technical documentation for what they have developed (Larsen and Nielsen, 2011).

The literature demonstrates that AAU has been discussed broadly as an influential PBL model in engineering education (De Graaff and Kolmos, 2007), especially on the project characteristics of solving real-life problems and interdisciplinarity (Nielsen et al, 2008). So the PBL model at AAU has proven to be very popular with the students, who prefer real life engineering problems compared to hypothetical, academic problems and lectures. This has led to a highly beneficial co-operation with the local industry as a major of master thesises are proposed by companies (Larsen and Nielsen, 2011). Moreover, the recent studies have demonstrated Aalborg University is ranked as the best one of educating engineers in institutions in Denmark (Kolmos and Holgaard, 2010). Due to the success, the UNESCO chair in PBL has been settled at AAU (http://www.ucpbl.net/), aiming to create a global society for researchers and academic staff working with PBL.

Conclusion

It is clearly evident that the ability to solve problems creatively is an essential attribute for an engineer. According to the literature, the development of creativity in engineering education can be enabled through a series of strategies, which include using thinking tools, building a learning environment conductive to creativity, and learning by problem-solving. Problem-Based Learning is a good example of fostering creative engineers since it provides a collaborative knowledge-building and self-directed learning environment, under the core philosophy of "student-centered learning". Due to the potential of developing creativity, PBL has been employed broadly in different areas of higher education and a growing number of institutions, such as Aalborg University in Denmark. However, to apply strategies to developing creativity and high-level thinking skills should not become overburden for both students and teachers. To be effective and attractive, the techniques should be introduced throughout the curriculum and related to interesting topics those engineering students are concerned. Therefore, the key

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of developing creativity in engineering education is to help students realize their creative potential, understand what is known about creativity, and increase confidence of being creative engineers in their future careers.

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