*Int. J. Engng Ed.* Vol. 20, No. 5, pp. 801–808, 2004
Printed in Great Britain.

0949-149X/91 $3.00+0.00


# Teaching Creativity in Engineering*

ZHIQIANG (ERIC) LIU and DIETER J. SCHÖNWETTER
*University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada. E-mail: schnwet@ms.umanitoba.ca*

*Creativity education in engineering is an ongoing critical issue for universities, in the sense that it helps meet the expectations for professional engineers, as well as completes the intellectual development of individuals. However, the importance of implementing creativity education in the classroom has not been fully recognized. In this paper we reviewed recent publications in this regard, attempting to dissect what creativity means to engineers, and how they can overcome the blocks to creativity. Having comprehensively explored the creative process, we suggested an operable tool based on Treffinger's creative learning model that can be implemented in a classroom setting to facilitate creativity.*

## INTRODUCTION

*What is now proved was once only imagined* (Blake)

UNIVERSITIES are increasingly expected to provide more opportunities that foster and nurture creativity in engineering students [1]. The profession of engineering demands that engineers recognize, validate, and solve problems on their own or through team work. More importantly, they should demonstrate original and critical thinking, and creativeness and innovativeness in their methodologies [2]. In short, engineers need a creative mind to meet the advancing goal of the engineering profession — to design new products or systems and improve existing ones for the benefit of humankind [3]. Unfortunately, little has been done in many universities to place teaching emphasis on developing and facilitating creativity in their engineering students [4]. This paper reviews the current understanding of creativity and the creative process, attempts to identify and examine blocks to the development of creativity, and explores a teaching model that tends to foster creativity in engineering students.

## DEFINING CREATIVITY

Defining creativity is a daunting task, given the wide range of definitions [1, 5, 6]. People often come up with their own definitions of creativity, such as 'the ability to create' [7]. According to Random House Webster's Unabridged Dictionary (v3.0), creativity is 'the ability to transcend traditional ideas, rules, patterns, relationships, or the like, and to create meaningful new ideas, forms, methods, interpretations, etc.' This definition stresses the creation of something innovative and useful from pre-existing knowledge and experience, which agrees with how most engineers see creativity [8]. In other words, creative engineers should be able to explore and scrutinize the available data or information and generate novel solutions to specific engineering problems or to the production of a unique product [9].

* Accepted 20 January 2004.

### *Stages of creativity*

According to Taylor [10], creativity is perceived as a hierarchy from a low to a progressively higher level (see Fig. 1):

- The first level includes **expressive creativity**, the ability to develop a unique idea with no concern about its quality. This is illustrated by the engineering student who is asked to design a shelter using two square meters of cardboard, three meters of string, and thirty centimeters of duct tape, and invited to sleep in it for one night.
- The second level is defined as **technical creativity**, the proficiency to create products with consummate skills, but with little expressive spontaneity. For example, an engineering student emulates the exact behaviors in a laboratory assignment as modeled by the instructor, replicating the production of an existing structure, such as a bridge.
- The third level includes **inventive creativity**, the ability to develop a new use of old parts and new ways of seeing old things in an ingenious manner. Here the engineering student creates a prototype, the first of its kind based on the process of combining older ideas and synthesizing them into a new product.
- The fourth level, **innovative creativity**, is the ability to penetrate foundational principles or establish a school of thought, and formulate innovative departures. The engineering student is able to 'think outside the box', to move beyond the current thinking of engineering and develop a new way of creating and designing. For example, students are asked to design a motor driven by water as fuel.
- The fifth and highest level is **emergent creativity**, the ability to incorporate the most abstract

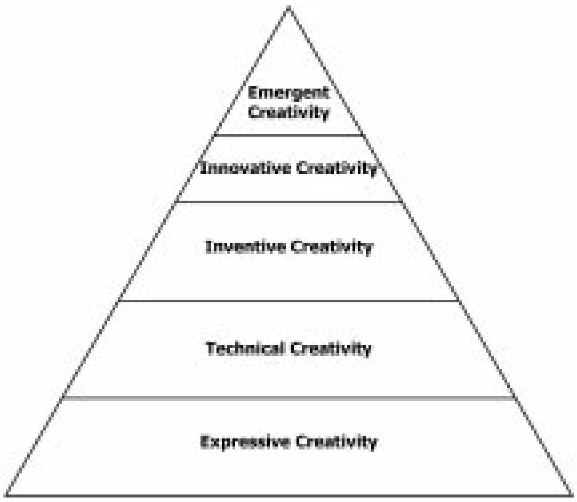


Fig. 1. Taylor's hierarchy of creativity.

ideational principles or assumptions underlying a body of knowledge, as in the example of Einstein's work on general relativity.

For engineers, setting the highest goal at a level of 'innovative creativity' or 'effective novelty' [11] may be more realistic and achievable, considering the facts that engineering is a profession where scientific principles or findings are applied to produce useful products and services [2], and novelty is the single common element for numerous definitions of creativity [6].

*Divergent thinking and creativity*

One major component of creativity is divergent thinking, which involves producing new and possibly multiple solutions or answers or ideas to a problem or question from the available information [5]. It is measured by four main characteristics.

- The first one is **fluency**, the ability to generate many responses or ideas. To achieve high fluency requires much training in brainstorming, with emphasis on the quantity of responses.
- The second is **flexibility**, the ability to change the form, modify information, or shift perspectives. In other words, a flexible student is able to generate varied ideas from new perspectives.
- The third is **originality** or the ability to generate unusual or novel responses. Here an engineering student should be encouraged to practice bold imagination, and take risks of identifying and rationalizing the novelty.
- The fourth is **elaboration**, the ability to embellish an idea with details. To elaborate a novel idea and finally turn it into an innovative product requires a solid and broad knowledge of science and engineering.

**Team-working** should be encouraged here in order to bring a diversity of expertise together. In general, personalities such as the following are needed to motivate divergent thinking [4]:

- openness
- flexibility
- nonconformity
- willingness to take risks
- tolerance of ambiguity
- the courage of one's own convictions.

*Convergent thinking and creativity*

Convergent thinking centers on deriving the single best solution or answer to a given problem or question from the available information [11]. Convergent thinking differs qualitatively from divergent thinking in that the latter leads to the variability whereas the former leads to the singularity of information production [11]. Although divergent thinking is believed to be the cognitive basis of creativity [5], both schools of thinking are interactively involved in the development of creativity [11, 12]. Interestingly, convergent thinking may play a more important role in the early stage of creativity development. According to a threshold model, a minimum level of conventional and factual knowledge (singularity) is needed to produce new ideas (variability) [11]. Whatsoever, creative engineers are usually skilled at both divergent and convergent thinking [13].

## THE CREATIVE PROCESS

Creativity involves the process of creating or creative activities [14]. The creative process, starting from a problem or question, has been described in many ways [1, 15, 16], and basically contains four phases: preparation, generation, incubation, and verification [1].

**The preparation phase** includes defining, reformulating, and redefining the problem or question. 'The formulation of a problem is often more essential than its solution, which may be merely a matter of mathematical or experimental skill. To raise new questions, new possibilities, to regard old problems from a new angle, requires creative imagination and marks real advance in science', claimed Einstein and Infeld [17]. The way a problem is framed often reflects the purpose [1], which directs diverse means of mind towards creative ends [18]. For example, a paradigm shift from plastic recycling to the invention of a new generation of degradable plastics have occurred [19] by reformatting the question 'how do we dispose of plastics?' to 'how do we make disposable plastics?'

The **phase of generation**, also described as brainstorming [20], involves shaking out all associative ideas or concepts to the problem. Engineering students, after having defined, reformulated, and redefined the problem or question, move towards generating solutions as many as possible. Many creative brainstorming techniques, including mind mapping, symbolic analogy, forced connections, and manipulative verbs [14] can be used at this stage. These techniques will be discussed in detail later in the paper.

The **incubation phase** is a period of full relaxation (e.g. sleeping or showering) or relaxed attention (e.g. leisure biking), which allows one's subconscious intelligence to suggest solutions. Reportedly, people often generate a potential idea after a certain time of incubation [21]. For example, many solutions to difficult challenges can often be resolved after a break away from active processing [22]. The most renowned example may be that German chemist Friedrich August Kekule von Stadonitz cracked the ring structure of benzene after a *schnapps*, in which he dreamingly saw a whirling serpent that was swallowing its tail.

The **verification phase** includes analyzing, clustering, and evaluating all the solutions or ideas, and planning and implementing actions [1]. For example, an engineering student attempting to solve an engineering problem begins by collecting all possible reasons and solutions by brainstorming, and then analyzes, clusters, and evaluates the solutions based on his or her experience and knowledge. A few most possible solutions will then be chosen. Next, the student focuses on planning the action such as the design of experiments. Once planned, the student can move toward implementing the actions needed to solve the problem, starting with experimentation of the most possible solution.

Not included in this literature is an evaluation phase of the effectiveness with which the student was able to implement the solution efficiently. We propose that as part of the creative development of the future engineer, students engage in reflecting on the effectiveness of their creative approach to solving the problem. Flow diagrams capturing the variety of processes entertained or engaged to accomplish the solution provide meaningful visuals to the student as to patterns of problem solving. This evaluative reflection provides further learning for improving future means of solving problems based on past experiences.

## BLOCKS TO CREATIVITY

The development of creativity is affected by personal and situational factors [23]. Situational factors (e.g. mood, reward, motivation, and attention) may exert less adverse influence than personal factors (e.g. knowledge, skills, and attitude) which may eventually eradicate creativity. It is the instructor's responsibility to teach students how to recognize and remove blocks to creativity [8]. Some of the common blocks include [8]:

- *Fear of the unknown.* Avoiding unclear situations; overweighing the unknown versus the known; and needing to know the future before going forward. Solution: 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. Solution: 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 pushy behavior which may influence others; hesitating to stand up for what one believes; and failing to make oneself heard. Solution: 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. Solution: 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 the importance of resources (i.e. people and things) in one's environment. Solution: 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. Solution: 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 the unusual. Solution: 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. Solution: providing students opportunities to make things as they wish 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. Solution: 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. Solution: providing students with opportunities to reflect and evaluate their methods of creative problem solving.

Ironically, intelligence may also challenge creativity [8]. Many students with orthodox education tend to have their thinking confined in specifically structured patterns, and rarely show variation in their thoughts. Although these students are more likely to effectively accomplish short-term tasks (e.g. assignments in a course), they may be unable to deal with real-world problems, which are constantly in flux [24]. Solution for these students is to be part of team or group projects in which other team members role model thought process variation in solving problems.

## ENGAGING, ACTIVATING, AND ENCOURAGING CREATIVITY IN THE CLASSROOM

Since creativity emanates from problems, it seems more natural for engineering students to gain creativity through practice of problem-solving, as they are inevitably expected to be effective and creative problem-solvers [2]. Teaching the students systematic approaches to solving problems is very important [25], because understanding the routes of problem-solving may help illuminate how to activate creativity in the students. Hoover and Feldhusen [26] proposed a theoretical model of the systematic problem-solving pathway, starting from sensing the existence of a problem and ending up with verified solutions (see Fig. 2). Treffinger *et al.* [27] reported a simpler version, which is based on four components: understanding the challenge, generating ideas, preparing for action, and planning approach. An effective teaching strategy would thus be to walk students through the pathways using several engineering problems, in order to demonstrate the usefulness and efficiency of following through the strategy.

Following the creative process and systematic pathways of problem-solving, the creative learning model proposed by Treffinger *et al.* [28] is a powerful tool for an instructor to stimulate and develop creativity in engineering students. The model 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. Each of these is further detailed below.

*Level 1: Learning and using basic thinking tools*

The instructor begins with direct instruction in using thinking tools, and then incorporates the tools into course contents. Note that students need to know how to use the tools specifically and effectively, in order to facilitate the idea generation process in the creative process [1]. Sample thinking tools include:

- analogical thinking [29]
- brainstorming [29–31]
- mind mapping [14]
- attribute listing [29, 30]
- morphological syntheses [29]
- forced relationships or connections [14, 30]
- idea checklists [29, 30]
- manipulative verbs [14, 2 0].

See the references [24, 29, 30, 32] for information on other thinking tools.

**Analogical thinking** is to transfer an idea from one context to a new one [29]. Actually, the invention of Pringles potato chips is a result of analogical thinking [29]: the idea was inspired by the analogy of wet leaves, which stack compactly and do not destroy themselves. To implement this technique, students are encouraged to deliberately ask questions like 'What else is like this?', 'What have others done?', 'Where can I find an idea?' and 'What ideas can I modify to fit my problem?'

As the most frequently used tool to generate new ideas [14, 23], **brainstorming** means bouncing ideas out about a subject, no matter how wild or ridiculous they may appear like. In order to obtain high-quality results, the instructor and students need to observe some rules of thumb. According to Rossiter and Lilien [31], the instructor should follow six principles of brainstorming:

1. Give instructions and emphasize the number not quality of ideas [20].

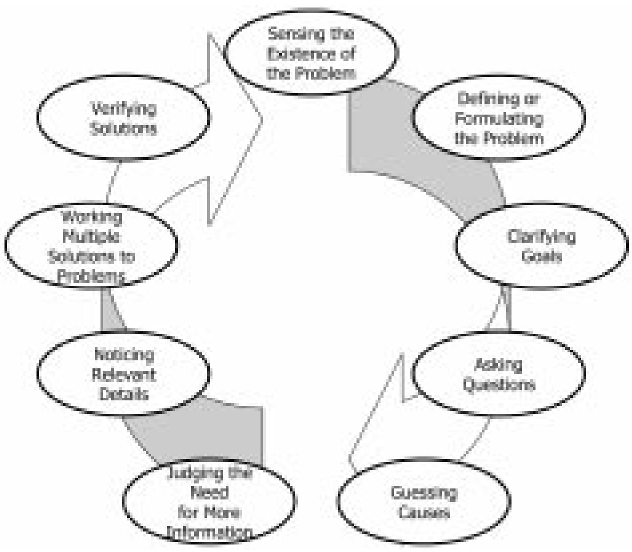


Fig. 2. Problem-solving pathway (adapted from Hoover and Feldhausen, 1994).

2. Set a difficult goal for the number of ideas.
3. Ask individuals, not groups to generate the initial ideas.
4. Use groups to integrate and refine the ideas.
5. Ask individuals to provide the final ratings and to select the best ideas.
6. Keep the time short for brainstorming.

In addition, the instructor should encourage originality and elaboration of any ideas, but not criticize and evaluate the ideas until all responses are collected.

**Mind mapping** is actually a variant of brainstorming. It involves tracking and recording our thoughts in pictures (or sketches) as well as words [14]. This technique tends to reflect our thinking more accurately than brainstorming does, because we think in both words and pictures.

While brainstorming or mind mapping is a general procedure, **attribute listing** is a technique specifically oriented towards idea-finding. By this technique the students begin by identifying all characteristics or attributes of the subject (e.g. product or process) being studied, and then think up ways to change, modify, or improve each attribute [30]. **Morphological synthesis**, and **forced relationships or connections** are actually elaborations of the technique of attribute listing [14, 29]. After the list of all attributes required for the subject is generated, the students are asked to create attribute sub-lists by putting as many alternatives under each attribute, and then to take one item from each sub-list and combine them into new forms.

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 [30]. A sample checklist [30] for a device improvement may include these entries:

- ways to put the device to other uses;
- ways to modify the device;
- ways to rearrange the device;
- ways to magnify the device;
- ways to reduce the device.

Similar to idea checklists, the technique of **manipulative verbs** utilizes a series of verbs to help seeing a subject from a fresh perspective [14, 20]. Choose the verbs that suggest the ways the subject can be manipulated (e.g. alter its shape, function, and size). Sample verbs include magnify, minify, rearrange, alter, modify, substitute, reverse, and combine [14, 20].

Learning and using basic thinking tools open up more channels for students to highly-efficient divergent thinking (with concurrent gains of fluency, flexibility, originality, and elaboration), and thus help students to engage in the initial stages of the creative process (i.e. preparation and generation). However, more is required for creativity to be fully activated. Students require exposure and adoption of a systematic process of problem solving.

*Level 2: Learning and practicing a systematic process of problem solving*

The instructor continues by providing opportunities for students to learn and practice systematic steps or processes for effective problem solving. Level 2 extends the use of the tools from Level 1, and provides a structural methodology for their applications in solving problems. It is critical for the instructor to ensure that the students understand the systematic problem-solving pathways, and promote the 'right' practice problems. Basically, individuals tend to work with the problems associated with their needs, values and interests, which are more likely to motivate them for problem construction and creative thinking [33]. In addition, the problems should not be too challenging for the students. Although many believe that more challenging problems lead to more creative ideas, an optimal level of challenge exists for effective problem solving — moderately challenged students normally show the best results [34, 35]. Example teaching techniques include case studies, simulations, role playing, and group or team work [27, 36, 37].

In case studies, the instructor poses specific situations or cases, and ask students to generate potential solutions and evaluate them [37, 38]. Although the selection of cases depends on a specific curriculum, Felder and Brent [38] suggested the involvement of current global issues relevant to engineering, such as environmental/economic tradeoffs, problems related to globalization (e.g. moving of production facilities to other countries), and pros and cons of government regulation of private industry. Higher-level challenges can be further raised by occasionally introducing case studies of real-life industrial problems [38] or problems from current research projects [39]. The students are asked to identify what they would need to know to solve the problems and how they would go about obtaining the needed information [38].

Students can also learn problem-solving skills through computer simulations. Here the students are required to solve problems through using computer software. In fact, computer simulations have been used to conduct extensive parametric studies and process optimization [38]. For mechanical engineering students, such simulation could be analyzing the mechanical behavior of a steel-constructed bridge with a constant load of traffic, using a finite element analysis software package (e.g. ABAQUS). The key in computer simulations is not to simulate the product itself (e.g. the bridge), but to test, evaluate or validate the situations (e.g. the constant heavy traffic) where the product is supposed to function [40]. Extensive drilling engineering students in computer simulations is more necessary than ever, because the simulations are often more cost-effective than physical experimentations, and have been used in almost all areas of engineering.

Role-playing is to have students, acting as identified key factors of a problem, interacting with one another, and asking them to conclude what combinations of the factors would eventually solve the problem. For example, getting students to role-play molecules in a reactive gas would teach them more about the dynamic behavior of a given system than would a standard lecture [41].

Even though an engineering problem could be resolved independently, more than ever it would involve interactive collaboration through group or team work. Actually, case studies, role-playing, and practice problems could be implemented in a form of team-work. Members in a group or team can provide one another with feedback, and challenge one another's conclusions and reasoning. More importantly, they can teach and encourage one another through team-work [38] while gaining interpersonal and team-player skills which are also very important to a professional engineer [42].

Training in both divergent and convergent thinking (e.g. deriving solutions by computer simulation) is involved at this level. Having been exposed to the full stages of the creative process through solving practice problems, students should have a creative mind, which will further mature through working with real problems in Level 3.

*Level 3: Working with real problems*

The objective of this level is to improve students' capability of and effectiveness in handling real-life problems and challenges. Working with others at this level, the instructor serves as a facilitator. Unlike level 2, where the students learn the methodologies others have used to solve problems (e.g. by means of case studies), students must experience first-hand through hands-on unsolved problems at Level 3. In fact, students are expected to act as professional engineers, using the skills learned in Levels 1 and 2 to generate ideas, to identify the key issues, and finally, to solve realistic problems within certain restrictions (e.g. time-frame, cost, and materials).

Example of real problems include personal or group concerns, community needs or issues, new products (programs or actions), individual/organizational needs or opportunities, and special projects (e.g. the instructor's own research projects). The success of gathering real problems or cases requires the instructor to maintain current contacts with industries and keep to abreast of contemporary developments of the related area. Sending students to an environment where they would be going to after graduation would empower them with confidence and challenge them with the real responsibilities and pressures of a professional engineer.

## CONCLUSIONS

Understanding creativity and the creative process in the context of engineering is essential for an instructor to be able to foster creativity in engineering students. In addition to teaching students to identify and remove the blocks to creativity, the instructor can use the creative learning model to further facilitate and nurture students' creativity through teaching strategies oriented towards problem-solving. Success of the CASE (Creativity in Arts, Science and Engineering) project [43] may suggest that creativity potential often lies dormant in most students and it is the instructor's responsibility to unblock the barriers and unlock or ignite creativity.

Teaching creativity in a university setting does not mean that every graduate will become an Edison or Einstein. It does, however, suggest that Students might become creatively productive in meaningful ways. Teaching with a purpose of facilitating creativity would also help students learn more about their own creative abilities, and attain greater personal and professional success and satisfaction through creative efforts [28].

## REFERENCES

1. C. Baillie, Enhancing creativity in engineering students, *Eng. Sci. Educ. J.*, **11** (2002) pp. 185–192.
2. M. C. Shaw, *Engineering Problem Solving: A Classical Perspective*, Noyes Publications, Norwich, NY (2001).
3. J. C. Martin, Complete professionalism for engineers, in *Frontiers in Education Conference*, IEEE, Washington, DC (1991).
4. D. H. Cropley, and A. J. Cropley, Creativity and innovation in systems engineering, in *Systems Engineering Test and Evaluation Conference: Conceiving, Producing and Guaranteeing Quality Systems*, Systems Engineering Society of Australia, Adelaide, Australia (1999).
5. J. P. Guilford, Creativity, *Am. Psychol.*, **5**, 1950, pp. 444–454.
6. D. N. Morgan, Creativity today, *J. Aesthet.*, **12**, 1953, pp. 1–24.
7. D. F. Hardy, Students' Definitions of Creativity. http://www.csun.edu/~vcpsy00/creativity/survey.htm
8. S. J. E. Christiano, and M. R. Ramires, Creativity in the classroom: special concerns and insights, in *Frontiers in Education Conference*, IEEE, Washington, DC (1993).
9. J. P. Guilford, *The Nature of Human Intelligence*, McGraw-Hill, New York (1967).
10. I. A. Taylor, An emerging view of creative actions, in I. A. Taylor, and J. W. Getzels (eds.) *Perspectives in Creativity*, Aldine, Chicago (1975).
11. A. J. Cropley, Creativity and cognition: producing effective novelty, *Roeper Rev.*, **21** (1999) pp. 253–260.

12. M. I. Isaak, and M. A. Just, Constraints on thinking in insight and invention, in R. J. Sternberg, and J. E. Davidson (eds.) *The Nature of Insight*, Bradford Book, London (1995).
13. C. Facaoaru, *Kreativität in Wissenschaft und Technik: Operationalisierung von Problemlösefähigkeiten und kognitiven Stilen*, Verlag Hans Huber, Bern (1985).
14. A. P. Oslapas, Beyond brainstorming: creative problem-solving techniques, in *Frontiers in Education Conference*, IEEE, Washington, DC (1993).
15. A. J. Cropley, and K. K. Urban, Programs and strategies for nurturing creativity, in K. Heller, F. Moenks, R. J. Sternberg, and R. Subotnik (eds.) *International Handbook of Giftedness and Talent*, Pergamon, Oxford (2000).
16. G. Wallas, *The Art of Thought*, Harcourt & Brace, New York (1926).
17. A. Einstein, and L. Infeld, *The Evolution of Physics: The Growth of Ideas from Early Concepts to Relativity and Quanta*, Simon and Schuster, New York (1938).
18. D. N. Perkins, *The Mind's Best Work*, Harvard University Press, Cambridge, MA (1981).
19. Z. LIU, *Study on Processing and Preparation of Thermoplastic Starch and Starch-Based Degradable Materials*, Ph.D. dissertation, Zhejiang University, Hangzhou (1998).
20. A. F. Osborn, *Applied Imagination: Principles and Procedures of Creative Problem-Solving*, Scribner, New York (1963).
21. W. Tomic, and A. Brouwers, Idea generating among secondary school teachers, *Catal. Change*, **28**, 1999, pp. 5–7.
22. B. A. Browne, and D. F. Cruse, The incubation effect: Illusion or illumination? *Hum. Perform.*, **1**, 1988, pp. 177–185.
23. S. Davis, and J. J. Palladino, *Psychology*, Prentice-Hall, New York (2000).
24. J. S. Dacey, *Fundamental of Creative Thinking*, Lexington Books, New York (1989).
25. M. T. H. Chi, and R. D. Koeske, Network representation of a child's dinosaur knowledge, *Devel. Psychol.*, **19**, 1983 pp. 29–33.
26. S. M. Hoover, and J. F. Feldhausen, Scientific problem solving and problem finding: a theoretical model, in M. A. Runco (ed.) *Problem Finding, Problem Solving and Creativity*, Ablex Publishing Company, Norwood, NJ (1994).
27. D. J. Treffinger, S. G. Isaksen, and K. B. Dorval, *Creative Problem Solving: An Introduction*, Prufrock Press, Waco, TX (2000).
28. D. J. Treffinger, S. G. Isaksen, and K. B. Dorval, Creative problem solving: an overview, in M. A. Runco (ed.) *Problem Finding, Problem Solving and Creativity*, Ablex Publishing Company, Norwood, NJ (1994).
29. G. A. Davis, *Creativity Is Forever (3rd Edition)*, Kendall/Hunt Publishers, Dubuque, Iowa (1992).
30. P. H. Wright, *Introduction to Engineering (Second Edition)*, John Wiley & Sons, New York (1994).
31. J. R. Rossiter, and G. L. Lilien, New 'brainstorming' principles, *Aust. J. Management*, **19**, 1994, pp. 61–72.
32. E. de Bono, *Mind Games*, Dorling Kindersley, London (1995).
33. M. D. Mumford, R. Reiter-Palmon, and M. R. Redmond, Problem construction and cognition: Applying problem representations in ill-defined domains, in M. A. Runco (ed.) *Problem Finding, Problem Solving and Creativity*, Ablex Publishing Company, Norwood, NJ (1994).
34. T. E. Heinzen, Moderate challenge increases ideational fluency, *Creativity Res. J.*, **2** (1989) pp. 223–226.
35. E. L. Deci, R. J. Vallerand, L. G. Pelletier, and R. M. Ryan, Motivation and education: The self-determination perspective, *Educ. Psychol.*, **26**, 1991, pp. 325–346.
36. D. R. Woods, Problem-based learning, especially in the context of large classes. *http://chemeng.mcmaster.ca/pbl/pbl.htm*
37. D. R. Woods, *Instructor's Guide For How To Gain The Most From Problem Based Learning*, The Author, Waterdown, ON (1996).
38. R. M. Felder, and R. Brent, Designing and teaching courses to satisfy the ABET engineering criteria, *J. Eng. Educ.*, **92**, 2003, pp. 7–25.
39. R. G. Hadgraft, Problem-based learning: a vital step towards a new work environment, *Int. J. Eng. Educ.*, **14**, 1998, pp. 14–23.
40. B. T. Christensen, *The Creative Process and Reality*, Aarhus Universitet, Risskov, Denmark (2002).
41. R. M. Felder, D. R. Woods, J. E. Stice, and A. Rugarcia, The future of engineering education II. Teaching methods that work, *Chem. Eng. Educ.*, **34**, 2000, pp. 26–39.
42. American Engineering Accreditation Commission, *2003–2004 Criteria for Accrediting Engineering Programs*, Accreditation Board for Engineering and Technology, Inc., Baltimore, MD (2002).
43. S. DeWulf, and C. Baillie, *CASE: Creativity in Art, Science and Engineering*, DfEE, London (1998).

**Zhiqiang Liu** is Postdoctoral Fellow in the Department of Food Science at the University of Manitoba in Canada. His research has focused on industrial utilization of natural biopolymers, with emphasis on carbohydrates. He has authored or co-authored twenty-five refereed publications, and owned two patents. He has B.Sc. degree in Materials Science, and D.Eng. degree in Polymeric Materials from the Zhejiang University in China. He has Certification in Higher Education Teaching (CHET) from the University of Manitoba.

**Dieter J. Schönwetter** is the Associate Director of University Teaching Services, an adjunct to the Faculty of Education and the Department of Psychology, and is a faculty development specialist. As a social psychologist, he specializes in the social dynamic interactions between effective teaching behaviors and university student learning outcomes, particularly focusing on helpless and oriented students. Since joining the University of Manitoba in 1999, his primary responsibilities are for faculty development of future professorates, coordination of the first-year experience of 1200 of the 4500 first-year students, graduate training, and research.