Proc. Natl. Sci. Counc. ROC(D)
Vol. 12, No. 2, 2002. pp. 64-72

Implementation of an Innovative Curriculum to Cultivate Technological Creativity in Engineering Students

PEI-FEN CHANG* AND SHU-SAN HSIAU**

**Center for Teacher Education*
National Central University
Chungli, Taiwan, R.O.C.
***Department of Mechanical Engineering*
National Central University
Chungli, Taiwan, R.O.C.

(Received November 13, 2001; Accepted April 30, 2002)

ABSTRACT

This study investigates the effects of a series of instructional activities in engineering classrooms on students' self-reported development of professional competencies. The teachers' experiences in developing the course, "Creative Mechanical Design," for technological creativity cultivation are discussed in this paper. In order to determine directions for improvement, both quantitative and qualitative data from Torrance's Test of Creative Thinking, surveys, and semi-structured interviews were collected and analyzed to evaluate the curriculum and to understand the students' learning difficulties. Overall, the results of Torrance's Test of Creative Thinking showed that students' performance in flexibility, fluency, and originality all significantly improved after they were taught creative problem-solving skills and received the training procedures to design mechanical products. Based on the response data from student interviews and questionnaires, the most rewarding instructional activities in this course were the creativity contest, development of a team project, and communication skills. In addition, the top three abilities attained by students were teamwork skills, design experience, and problem-solving skills. Students indicated that the impact of this course, particularly involving topic selection and problem-solving of their team project, extended beyond enhancement of mechanical competence and their ability to function well as a team.

Key Words: curriculum development, technological creativity, project-based learning

I. Introduction

Traditional education for engineering students focuses on classroom indoctrination of domain knowledge, and most problems given to students in class are well defined with only one correct solution. Under current engineering training, students are asked to solve these "textbook" problems, which generally are simple, formulated in particular forms, and have standardized approaches and answers. In industry, however, engineers often face complicated problems with no immediate or absolute answers. Hence, engineering graduates often find that the techniques they learned in college are not practical for solving industrial problems.

Even though many curricular projects do indeed concern the natural environment, few projects, however, treat the industrial environment as part of the contemporary human environment and are thus amenable to project-based learning (Tal, Dori, & Lazarowitz, 2000). In order to provide students with the experience of solving real-life problems similar to ones they will encounter as engineers, a course of "Open-ended Creative Mechanical Design" has been offered in the Department of Mechanical Engineering at National Central University since 1997 (Hsiau, 1998). The purposes of this course are to: (1) inspire students' technological creativity via learning modules, (2) train students to solve open-ended industrial problems, and (3) emphasize the importance of teamwork and communication skills in the simulated industrial environment.

Basically, the course allows students to experience first-hand the reality of applying creative and technical skills to the world outside the academic environment. The multi-media courseware is well established and has twice received awards from the Ministry of Education in Taiwan.

Survey results for the last 3 years have indicated that the impact of such an open-ended project-based course extends beyond the enhancement of mechanical competence and that it provides students with a sense of achievement and satisfaction (Hsiau, 1998). However, an evaluation of the effects of the curriculum and the students' learning of creativity has not been conducted in order to look for directions for improvement. To remedy problems associated with traditional assessments, we developed a framework for an on-going assessment system that incorporates both quantitative and qualitative methods.

In the following section, we first review the literature pertaining to facilitating creative problem-solving skills by our instructional activities. Second, we synthesize previous research studies related to enhancing the problem-solving confidence of college students by project-based learning.

II. Theoretical Framework

1. Creative Problem-Solving Skills

Creative problem solving is a well-defined methodology that encourages students to brainstorm and generate sketchy ideas, analyze the ideas, implement a plan, and finally evaluate the plan (Lumsdaine & Lumsdaine, 1995). The creative process has traditionally been described in five steps (Wallas, 1926). The first is a period of *preparation* with a set of problematic issues that are interesting and which arouse curiosity. The second phase consists of a period of *incubation*, during which time unusual connections are likely to be made. The third component is *insight*, sometimes called the "Aha!" moment, i.e., the instant when the pieces of the puzzle fall together. The fourth component is *evaluation*, when the person must decide whether the insight is valuable and worth pursuing, i.e., the period for deciding which ideas to develop. The fifth and last component of the process is *elaboration*, which is, of all, probably the one that takes up the most time and involves the hardest work. These categories are used to describe how creative people work, and in reality the five stages are not exclusive, but typically overlap and recur several times before the process is completed. Each stage involves challenges and problem solving, trial and error, correction, and action (da Silveira & Scavarda-do-Carmo, 1999).

Many professionals involved in the production aspects of engineering and technology agree that a reasonable view of the creative thinking process follows these steps: find the "mess," find the facts, find the problem, find the ideas, find the solution, find the acceptance, and find a new mess (Runco, 1994). Further, recent results from a variety of disciplines (Torrance, 1988; Russ, 1999; Epstein, 2000) seem to support the view that there are at least three major features of the creative process from the perspective of the individual: (1) ideational fluency or the ability to generate many ideas, (2) tolerance or the ability to tolerate negative feelings, and (3) intrinsic motivation.

2. Project-based Learning

Kember (2001) evaluated beliefs about knowledge and the process of college students' learning and concluded that development was a gradual process across the college years. Students do not develop higher-order epistemological beliefs if teaching and assessments reflect factual material verified by an authority. A key step in exposing students to an alternative belief set is for teachers to incorporate into their courses a significant proportion of teaching which is not didactic in nature.

Project-based learning emphasizes peer learning and active participation (Davie & Wells, 1991; Baillie & Walker, 1998; Blicblau & Steiner, 1998). These researchers argued that the successful efforts of teammates attract other members to offer their own unique contributions to elaboration of the group's creativity. Student-initiated project design fosters confidence and satisfaction. The hands-on experience of designing a team project stimulates curiosity and a desire to succeed. However, many students have never worked in a group before, and even at the college level, students receive little training on how to work as a team. Thus, only students who have been in a professional environment realize that most projects in industrial environments require a group effort. Furthermore, tomorrow's engineering challenges are very likely to contain elements of personal, social, technical, and environmental diversity for which creative solutions will need to be developed (Csikszentmihalyi, 1996; Mullins, Atman, & Shuman, 1999; Shankar & Eisenstein, 2000).

As Sarason (1990) also claimed, the degree of responsibility given to students in the traditional classroom is minimal since they are responsible only in the sense that they are expected to complete tasks assigned by teachers and in ways the teachers have indicated. More importantly, a project-based learning approach gives students the opportunity to determine what to do, not merely through reliance on rules, but rather on the basis of practical experience-based understanding. In order to improve upon the traditional learning environment, Tal, Dori, & Lazarowitz (2000) pointed out that the project-based approach resembles real life experiences. Students are responsible for their own learning, teachers oversee student teamwork, and community stakeholders are involved in school curriculum and assessment. In addition, Karnes, Shwedel, & Williams (1983) suggested the following characteristics of instruction for creative learning: (1) encouragement of children to pursue a chosen interest in depth; (2) learning based on needs rather than on a predetermined order or sequence of

Table 1. The Five Main Instructional Activities of the Course

Content outline	Learning activities
Significance of the technological creativity	1. Use outstanding student projects to illustrate how creativity can evolve into mechanical design.
	2. Brainstorm 30 possible functions of an item to demonstrate the power of group creativity.
Creative problem-solving (CPS) processes	3. Observe a problem pipeline and apply the CPS processes and teamwork skills to solve it.
Creative mechanical engineering design	4. Provide six basic principles for invention and the database of the US patent and trademark office.
	5. Apply these rules to modify the design of commercially available items.
Creativity contest (by individual)	6. Discuss the name and the rules for the creativity contest via WWW interactions.
	7. Proceed with peer-evaluation and selection of the top three most-creative vehicles.
Development of creative project designs (by group)	8. Develop a proposal based on all information gathered.
	9. Divide the students with three to five students per group. Each group must play roles of both presenters and observers.
	10. Make oral presentations to the class using PowerPoint.

instruction; (3) activities that are more complex and require more abstract and higher-level thinking processes; (4) greater flexibility in the use of materials, time, and resources; (5) higher expectations for independence and persistence to tasks; (6) greater encouragement of creative and productive thinking; (7) more interest in interpreting the behavior and feelings of self and others; and (8) more opportunities to broaden the base of knowledge and enhance language abilities.

III. Three Main Instructional Activities of the Course

Based on the features of the above research, we synthesized a teaching module that integrates creative problem-solving processes and procedures of creative project design to encourage students to integrate mechanical hands-on experiences with their learning of creative problem-solving processes (Table 1). Basically, this course is co-taught by teachers with expertise in such areas as fluid dynamics, mechatronics, educational psychology, and instructional design. Their multi-disciplinary backgrounds in course work provide experience and knowledge which establish a good foundation for conducting this study. For instance, three main instructional activities for the course are described in the next section.

1. Case Study for Creative Problem Solving

In order to enhance students' creative thinking skills, we asked students to solve a real-life problem that used both their analytical and teamwork skills. First of all, students were told to resolve an actual case of pipeline failure that had occurred in the basement of their departmental building. The failure was the result of a few days of water hammering on the check valve in the pipeline caused by some malfunction in the roof-top water reservoir level control system immediately after the water tank was cleaned. They were asked to outline what steps they would take in determining the causes and ways to resolve the problem. We then provided a mockup of the water tank control system with a real controller and sensors to allow students to solve this case. Students were encouraged to demonstrate the normal operation of the unit and what had gone wrong. We then provided students with the controller manual and allowed them to ask questions. After presenting their questions, they were asked to respond to several points. How should the system work normally? After applying the circuit theory, what kind of malfunctions would they propose which should be examined in order to diagnose the problem by mental imaginary and simulation? What would they do to verify that the simulation matched the real system? Finally, students were encouraged to devise a set of TTL logic circuits in place of the relay controller.

The purpose of this approach was to provide students with the experience of solving the kind of practical engineering problems they will encounter as professionals. We asked students to solve the above problem during two class sessions so that we could observe their creative problem-solving approach and be aware of any difficulties they were having in applying new concepts throughout the entire class. In addition, because the problem was real, it gave the students a chance to honestly measure their problem-solving skills against those of practicing engineers so that they could be better motivated towards realistic professional careers.

After the problem was presented, the students utilized the process of preparation, incubation, illumination, and verification (Wallas, 1926) in order to decide a course of action to discover the cause and find a solution to the problem pipeline. This was an activity to facilitate their techniques of problem definition, brainstorming, and teamwork. These aspects are important, since their previous education had not given them the opportunity to explore various possibilities. By discussing this case, we encouraged students to accommodate multiple aspects of a situation, so that they were better able to see alternative solutions. Even if they did not have the competency to completely solve the problem, the procedure of solving the case of the pipeline failure was valuable in that it stimulated their intellectual growth.

2. The Creativity Contest

After learning the concepts and skills related to the application of problem-solving techniques to daily life, students should be provided with opportunities to apply the engineering design process to product development. In order to enhance students' growth, an annual creativity contest is held, which constitutes a critical learning process since it is a creativity-inspiring activity in the natural environment (Kay, 1991). The object of the contest is to make whatever they desire which works with the environment and is appropriate to the theme; then, students design and build small-scale models of the structure. The rules for the contests are discussed by all students. In order to provide a basis for assessment, students must submit progress reports on the vehicle design and implementation, including test results. We have had three contests over the past three years in which students were required to: design a parachute which can carry a bottle of water dropped from a 20-m height; build a ship that is powered by a 3-volt d.c. motor; and design a rubber band-powered vehicle with no limitations on size or materials.

3. The Team Project for Creative Design

After lecturing on the concepts and skills related to the application of problem-solving techniques to daily life, we used the team project as a tool to foster the creativity of engineering students. During the second semester of the course, students worked in teams to carry out the mechanical design and testing of their prototypes (Hsiau, Wu, Yeh, & Tsai, 2000). Students were trained to make presentations to the class in order to learn how to analyze a problem, how to synthesize and attack that problem, and most importantly, how to communicate the results of their analyses and synthesis to the class. Each team discussed recent developments relevant to the project content, and invited other teachers to share their knowledge and experiences.

To provide a basis for the preliminary assessment, each team submitted a "Request For Proposal" which included the following eight elements: (1) an outline of essential elements; (2) objective; (3) problem identification; (4) methodology; (5) tentative outcome; (6) progress report; (7) manpower distribution; and (8) funding requisition. By fulfilling the above elements, we encouraged students to play the role of prospective engineers by investigating a phenomenon, developing a hypothesis, collecting and analyzing data, verifying and revising the hypothesis, and drawing conclusions. Each project included the following eight elements: (1) topic selection; (2) assessment of needs; (3) proposal request; (4) information gathering; (5) product drafting/designing; (6) product pilot-testing; (7) product fine-tuning; and (8) report writing and presentation. The following are examples of creative projects produced by students in the past 2 years: (1) an umbrella dryer; (2) an automatic light-sensing lamp; (3) an apple peeler with multiple blades; (4) an easy-to-dissemble roller blade; and (5) a parallel-parking device for an automobile. The online web address for the exhibition of these projects is http://cedesign.me.ncu.edu.tw.

In order to stimulate creative and effective learning from others' projects throughout the design process, each group must assume the roles of both presenters and observers. Generally the presenting group has the same members as the corresponding project design team. The presenting groups summarize the results of their work, highlighting the key progress related to the design project, after which the observing group makes suggestions as to how the project might have functioned more effectively. These student work groups not only create opportunities for students to learn from one another, but also enable students to participate and interact. The emphasis of the approach is to take responsibility as an active learner and to develop the ability to ask questions and make comments about projects carried out by other groups. Each team member is expected to be aware of the specific skills of others in order to achieve effective and collaborative working relationships. More importantly, each member needs to take into account other people's views.

IV. Methods

Three methods of data collection were analyzed: (1) Torrance's test of pre-test and post-test for creative thinking, (2) a course questionnaire, and (3) semi-structured interviews. The forty-six students enrolled in Open-Ended Creative Mechanical Design class took the Torrance's Test of Creative Thinking individually to assess their creative learning styles. The survey questionnaire was conducted to discover the impact of the course and those aspects of learning activity that most contribute to the cultivation of

Table 2. Comparison of the Means and Standard Deviations for Four Types of Creative Thinking on Torrance's Test of Creative Thinking

Type of Creativity	Mean	SD	*t*	α
Overall			2.05	0.050
Post-test	162.0667	50.274		
Pre-test	152.0000	46.109		
Flexibility			1.05	0.302
Post-test	42.6000	9.877		
Pre-test	40.1333	16.456		
Fluency			4.53	0.000
Post-test	67.8333	25.309		
Pre-test	56.2667	17.794		
Elaboration			-5.30	0.000
Post-test	23.2667	8.878		
Pre-test	34.3000	12.452		
Originality			4.28	0.000
Post-test	28.3667	12.489		
Pre-test	21.3000	5.706		

creativity in engineering students. At the end of the final presentations, students were asked to fill out a questionnaire addressing the projects and the courses' formats (Palmer, 2000). Some of the questions can be generally categorized as follows:

(1) Which modules of the course did you feel were the most rewarding?
(2) What skills have you learned in the course?
(3) Would you prefer a project with self-initiated format or faculty-initiated format?

Finally, five of the students volunteered to be interviewed 2 weeks later. The interviews were conducted to provide possible interpretations of the results of the survey. The five interview transcripts were coded, compared, and summarized in terms of the students' attitudes and perceptions toward the instructional activities. In this way, the reflection generated by the interview data could add to our understanding of rewards inherent in students' learning and could provide information suggesting how the instructional activities might be made more enjoyable, meaningful, and productive.

V. Results and Discussion

1. Torrance's Test of Creative Thinking

Results of Torrance's Test of Creative Thinking showed that except for the dimension of elaboration, students' performance in flexibility, fluency, and originality significantly improved after they were taught creative problem-solving skills and had received the training procedures for designing mechanical products in the course. Comparisons of the means and standard deviations on the four types of creative thinking for all students are presented in Table 2. After interviewing the participating students, we discovered that the lower elaboration scores of the test may have been due to the fact that students felt it was tiresome to repeat answers to the same items and therefore lacked the motivation to strive for good performance on their post-tests.

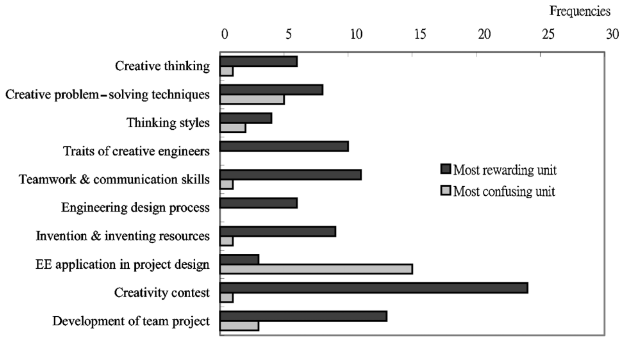

Fig. 1. Response to the research question: "Which Module of the Course Did You Feel Was the Most Rewarding?"

2. Questionnaire Results

Based on response data from the questionnaires, the most rewarding instructional activities, as identified by the students, were the creativity contest, and development of the team project and communication skills (Fig. 1). Students indicated that the contest provided them with the opportunity to practice what they had learned in a real-life design. On the other hand, the most confusing activity was the electric and electronic application of the project design. A possible explanation for this result may be the fact that the teacher included too many abstract concepts in a class period without effectively using handouts and audiovisual aids.

In addition, the top three skills that students gained in this course were (1) teamwork skills, (2) design experience and technical skills, and (2) problem-solving skills (Fig. 2). Furthermore, the interview questions were in an open-ended, semi-structured format that focused upon finding evidence to provide explanations or reasons behind the statistical results as well as difficulties.

3. Interview Protocols

Next, it was crucial to understand student perceptions in order to adapt instruction to the strengths, weaknesses, and preferences of different students (Snow, Corno, & Jack-

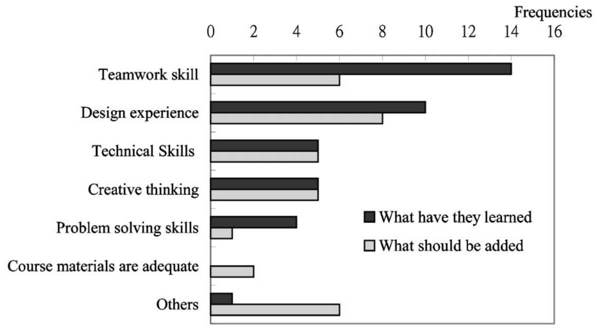

Fig. 2. Responses to the research question "What Skills Have You Learned from the Course?"

son, 1996). Therefore, interview transcripts were summarized to provide explanations or reasons behind the statistical results as well as students' learning difficulties in the course.

A. Problem-Solving and Design Skills Facilitated by the Instructional Activities

Contrary to faculty-initiated or industry-initiated project designs, students were willing to ask questions of their teachers or experienced factory workers as they search-ed for information or discussed ideas with their fellow group members. They would do everything they could to find solutions for their prototype design problems. As one student said:

> "Although I feel that our product still needs modifying, I've gained many experiences outside the classroom. This is unlike other classes over the past 3 years, where what we crammed were literally theories. I found that I preferred learning by doing because when we finally completed our product, we experienced a lot of excitement and satisfaction."

In addition, their interactions with experienced professionals increased the knowledge base and skills for their own design. A majority of students expressed much gratitude for their teacher's support and involvement. As one student stated:

> "The whole time we were there, he never said anything negative. It's amazing that he always had something positive to say. I think I've learned from him to be as creative as possible, always looking for new ideas, always challenging oneself to find something better."

He also felt that these interactions motivated him to learn more and develop the confidence to pursue his own interests. Students indicated that traditional pencil-and-paper tests assessed how much knowledge they had stored, whereas the case study allowed students to demonstrate ways that they were integrating their understanding of the material and applying it to engineering design contexts in a creative way:

> "I like this type of problem. I wish I had more of them because in other classes, you're just crunching numbers... I like these types of problems, 'cause it's more like real life, instead of dividing everything into certain subjects. I would like to do more of these in the future."

> "Design problems are more difficult than taking an exam because there are no right answers. They make you think. But in fact, you realize that there are no right answers. There is no one correct answer at all. You have to think and analyze how you present your thoughts."

These valuable experiences can enhance students' competence in problem solving. They learned how to confront both familiar and unfamiliar situations with confidence in order to provide a sense of achievement and satisfaction.

B. Problem-Finding Confidence Developed by Implementation of Team Projects

The project design allowed students to integrate their understanding of design procedures and apply them to engineering contexts in a creative way. Furthermore, they learned to determine the constraints within which the prototypes were being implemented and to work effectively within those constraints. If they encountered difficulties with their projects, they had to consider all possible solutions to overcome them. One student said:

> "We usually had our discussions during our free time, and we would set goals for ourselves and discuss them the next day. We put all our efforts into completing this project, so if we didn't accomplish this project design, we wouldn't feel disappointed or frustrated; at least we've learned something and that's the most precious experience for us."

In addition, students indicated that the non-judgmental atmosphere of this course made them feel secure in completely concentrating on the task at hand, since both the classroom atmosphere and teacher-student interactions were more positive than those encountered in other classes. One student indicated that it was during this class, that he finally had the courage to express himself and not to worry about what others might be thinking of him:

> "When I first started this class, I never had discussions with others.

I've never had discussions with others. I've never asked them questions, either. Now I do a lot of discussing because in this class, it's OK to ask for help or disagree with one another, including teachers."

Students were stimulated because they were on an similar level with their teachers, rather then being subordinates. These interactions motivated them to learn more and develop the confidence to pursue their own interests. Because students not only presented their project proposals and progress reports but also conducted peer-evaluation as a team, they enjoyed the feeling that what they had learned was a result of their group efforts.

An overall, current review of the literature seems to suggest that instructional practices should make a strong contribution to students' gains in professional competencies (Pirrie, Hamilton, & Wilson, 1999). Therefore, our instructional activities were developed to demonstrate how creative problem-solving skills and engineering procedures can be closely integrated and taught, and what the necessary knowledge and skills are which enhance students' abilities to become both creative and effective problem solvers.

C. Providing More Hands-on Experiences to Keep Students More Engaged in Their Learning of Creative Problem-Solving Processes

A review of the literature emphasized the need to provide more hands-on activities to help engineering students cope with real-world problems, since ideational fluency is important for identifying a problem, generating ideas, and arriving at a solution (Torrance, 1988; Russ, 1999; Epstein, 2000). It is clear from the present study that to be creative, students must be knowledgeable. They do not have to be as knowledgeable as possible, but they must have skills in the use of tools so that ideational fluency is optimized.

The results of this study also reveal that the majority of students perceived the course as an opportunity to broaden their abilities. Both the creativity contest and project design activities provided students ample opportunities to solve real-life open-ended problems, rather than dealing with textbook problems. Indeed, their interactions with experienced professionals increased the knowledge base and skills of their own design. Furthermore, some students felt that traditional engineering courses rely too heavily on theoretical, monotonous lecturing within the classroom environment and over-emphasize grades. Therefore, they believed that the oral reports explaining their team projects to the entire class were challenging and useful training that they received from almost no other engineering courses.

However, students found that even though they may have understood the theories and knowledge they had learned in the class, they still had a hard time trying to transfer the knowledge to the design of their team projects. Therefore, we teachers need to relate lesson contents to students' prior knowledge in order to make use of the knowledge and skills developed in other courses in combination with those emphasized in this course. For instance, teaching activities which involved more mechanical hands-on experiences might keep students more engaged in their learning of creative problem-solving processes.

D. Encouraging Self-Initiated Project-based Learning to Enhance Students' Problem-Discovering Attitudes

Topic selection initiated by students aims to develop the ability to approach a task for which they are not sure what they want to do at the beginning. In fact, this process of self discovery is the most important problem-finding process described by creative individuals (Runco, 1994). Students enjoyed the feeling that they had learned as a result of self-initiation and the experience of interacting with peers and teachers. Even if they had not discovered a new mechanical design or written a spectacular proposal, the procedure of the self-initiated project design was worthwhile to further develop their confidence in problem-solving and problem-finding processes.

However, some students claimed that the challenge of finding a topic was beyond their ability. It seemed that the vulnerability caused by their inadequate problem-finding skills tended to create unpleasant feelings of frustration. Some students were disturbed by the open-ended nature of the course materials. They felt more comfortable if the definitions of problems were fixed and given. This finding coincided with Kember's finding (Kember, 2001) that students with didactic beliefs tended to find the self-initiated learning process difficult and even traumatic. Still, there should be a form of teaching that requires students to discover content for themselves. In this way, they can come to see that the teacher is not the only source of knowledge. Also in this way, they can be exposed to the idea that knowledge is not black and white (Cabera, Colbeck, & Terenzini, 2001). In the present study, students indicated that the impact of a course like this, particularly the problem-finding process of the topic selection for their team project, extended beyond the enhancement of mechanical competence. We have demonstrated that students can be encouraged to develop a problem-discovery attitude in order to acquire the knowledge and skills of creativity. Students can then begin their evolution into seasoned engineers who can test, observe, incubate, and innovate. After all, the purpose of this project-based approach was to provide students with the experience of solving the kind of practical engineering problems they will encounter as professionals. We believe that engineering education is not so much about limited amounts of knowledge, but should foster life-long scientific habits and an intrinsic motivation to innovate and excel at improving the human environment.

VI. Conclusions

The goal of this course was to integrate theories of creative problem solving with project-based curriculum for the benefit of engineering students. In order to instill creativity into students' engineering background, we used a creativity contest and team project as tools to apply creative problem-solving skills to generate various possible solutions. Both quantitative and qualitative data from Torrance's Test of Creative Thinking, a questionnaire survey, and semi-structured interviews were collected and analyzed to evaluate the curriculum and to understand the students' learning difficulties, so that we could determine directions for improvement. Results of Torrance's Test show that students' performance in flexibility, fluency, and originality significantly improved during the course. Survey results indicated that the creativity contest, project design, and communication skills were the most rewarding activities of the course. In the future, we hope to develop a series of learning modules to provide students with the experience of solving practical problems they will encounter as professionals in more-enjoyable, meaningful, and productive ways.

Acknowledgment

The authors gratefully acknowledge financial support from the National Science Council, R.O.C., through projects NSC 89-2519-S-008-002 and NSC 89-2519-S-008-003. We also want to express our gratitude to Dr. Dau Chung Wang and Timothy Baker for their insightful perspectives.

References

Baillie, C., & Walker, P. (1998). Fostering creative thinking in student engineers. *European Journal of Engineering Education*, **23**, 35-44.

Blicblau, A. S., & Steiner, J. M. (1998). Fostering creativity through engineering projects. *European Journal of Engineering Education*, **23**, 55-65.

Cabera, A. F., Colbeck, C. L., & Terenzini, P. T. (2001). Developing performance indicators for assessing classroom teaching practices and student learning: the case of engineering. *Research in Higher Education*, **42**(3), 327-352.

Csikszentmihalyi, M. (1996). *Creativity: flow and the psychology of discovery and invention*. New York: Harper Perennial.

Davie, L., & Wells, R. (1991). Empowering the learner through computer-mediated communication. *American Journal of Distance Education*, **5**(1): 15-23.

da Silveira, M. A., & Scavarda-do-Carmo, L. C. (1999). Sequential and concurrent teaching: structuring hands-on methodology. *IEEE Transactions on Education*, **42**(2), 103-108.

Epstein, R. (2000). *The big book of creativity games: quick, fun activities for jumpstarting innovation*. New York: McGraw-Hill.

Hsiau, S. S. (1998). *A study of the course of open-ended, innovative and creative design in mechanical engineering*. Final project report for NSC 86-1512-S-008-001-EE. Taipei, Taiwan: National Science Council.

Hsiau, S. S., Wu, J. C., Yeh, T. L., & Tsai, S. J. (2000). The web-based learning environment for creative design course in CD-ROM. *Proceedings 2000 International Conference on Engineering Education*, Taipei, Taiwan.

Karnes, M. B., Shwedel, A. M., & Williams, M. (1983). Combining instructional models for young gifted children. *Teaching Exceptional Children*, **15**, 128-135.

Kay, S. (1991). Comparing the figural problem-solving and problem-finding behavior among professional, semi-professional, and non-artists. *Creativity Research Journal*, **4**(3), 233-252.

Kember, D. (2001). Beliefs about knowledge and the process of teaching and learning as a factor in adjusting to study in higher education. *Studies in Higher Education*, **26**(2), 205-221.

Lumsdaine, E., & Lumsdaine, M. (1995). *Creative problem solving: thinking skills for a changing world*. New York: McGraw-Hill.

Mullins, C. A., Atman, C. J., & Shuman, L. J. (1999). Freshman engineers' performance when solving design problems. *IEEE Transaction on Education*, **42**(4), 281-286.

Palmer, S. R. (October 2000). Student responses to activities designed to develop generic professional skills. *Journal of Professional Issues in Engineering Education and Practice*, 180-185.

Pirrie, A., Hamilton, S., & Wilson, V. (1999). Multidisciplinary education: some issues and concerns. *Educational Research*, **41**(3), 301-314.

Runco, M. A. (ed.) (1994). *Problem finding, problem solving, and creativity*. Norwood, NJ: Ablex.

Russ, S. W. (ed.) (1999). *Effect, creative experience, and psychological adjustment*. Philadelphia, PA: Brunner/Mazel.

Sarason, S. (1990). *The predictable failure of educational reform*. San Francisco: Jossey-Bass.

Shankar, P. M., & Eisenstein, B. A. (2000). Project-based instruction in wireless communications at the junior level. *IEEE Transaction on Education*, **43**(3), 245-249.

Snow, R. E., Corno, L., & Jackson, D. (1996). Individual differences in affective and cognitive functions. In: D.C. Berliner and R.C. Calfee (Eds.), *Handbook of educational psychology* (pp. 243-310). New York: Simon & Schuster Macmillan.

Tal, R. T., Dori, Y. J., & Lazarowitz, R. (2000). A project-based alternative assessment system. *Studies in Educational Evaluation*, **26**, 171-191.

Torrance, E. P. (1988). Teaching creative and gifted learners. In: M.C. Wittrock (Ed.) *Handbook of research on teaching* (pp. 630-647). New York: Macmillan.

Wallas, G. (1926). *The art of thought*. New York: Harcourt Brace Jovanovich.

Appendix
Interview Protocol Used in This Study

1. What was the most significant thing about the course for you? Why?
2. What do you think you did especially well on in this course?
3. What is the main challenge you encountered in this course?
4. Why were the creativity contest and project design the most rewarding activities in this course?
5. Where did the ideas for your project come from?
6. How did you and your teammates go about developing your idea/project?
7. How has this course affected your understanding of creative problem solving, interpersonal communication, and the design process?
8. How would you improve the effectiveness of this course?

技術創造力課程模組之發展與評估

張佩芬[*]　蕭述三[**]

[*] 國立中央大學教育學程中心
[**] 國立中央大學機械工程學系

摘　要

本研究應用創意思考的原則，整合於機械設計的教材與課程中，以建構一系列技術創造力之課程模組，以培養學生未來在技術領域和社會領域中所需具備之專業能力。本課程模擬團隊合作方式，要求學生以小組合作完成專題實作，期望經過創意思考教學之後，學生不但對創意機械設計的構思過程有深刻的認識，透過自己動手組裝測試，對於專題製作之流程與方法有更多的體驗。本研究根據托倫思創造力測驗、學生訪談、以及課程評量問卷之分析，藉以探討學生的學習困難及課程改進的方法。問卷之統計資料顯示，學生在創意實作上遭遇的最大困境為專業知識的不足，進一步透過訪談得知，除了專業知識以外，小組的分工合作、人力、物力和時間上的限制亦是實作上的難處。整體而言，學生在團隊合作、成品設計及問題解決等三個方面獲益最多。這份研究結果也強調需瞭解學生在專題式學習情境的困難，並於課程中提供更多實作機會，以期能擺脫以往根深蒂固的被動學習型態，而漸漸成為能測試、觀察、及實踐創意的優良工程師。