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InnovTech: Creativity and Innovation Learning Facility for Engineering Students*

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Engineering students are crammed with technical knowledge while learning at university. Students are always interested primarily in technical subjects, whether they are good at them or not. Most teaching programs constantly try to inject more and more specialist knowledge and skills into the young brains of the students. If these young engineering students are not innovative and creative at university, how can we expect them to behave so as engineers in society? How can such an ambition be achieved without the corresponding and indispensable support from our local universities, and primary and secondary schools? This is exactly the sort of problem that this paper aims to address—to teach engineering students to become professional engineers with society in mind, and with creative and innovative flair. This paper highlights the concepts of innovative and creative design, and aims to demonstrate that creativity, innovation, techno-economics, quality, social impact, and professional ethics can be taught and experienced at the same time, thus reinforcing that they are all linked together.

INTRODUCTION

THE TECHNICAL KNOWLEDGE taught in universities is barely sufficient to deal with the rapid change in today's business environment. For an engineer in demand, creativity is essential in a profoundly changing organizational world since creativity influences both organizations and their environments so fundamentally [1]. An engineer must contribute to technological innovation and new technologies by developing related new products and services, a contribution that is crucial to any organization's ability to sustain growth of net income [2].

THE LEARNING ENVIRONMENT PROBLEM

Most engineers find it difficult to cope with their working tasks. Projects are often fragmented, and information flow is frequently chaotic. Education offered within industry is often too high level, or worse, is not relevant, not offered where the engineer works, or not offered during the period between projects when the engineer actually has time to learn. Traditionally, managers who send engineers to classes or conferences have very little interest in understanding what value the program had for the engineer or the business that paid for it. Even worse, too many managers believe that if they lack a particular talent in their group, they can simply hire the talent they need and expect their problems to be solved immediately. A fresh-out-of-school, newly hired engineer takes six to twelve months to become professionally competent in a business environment. Businesses cannot ignore this time-to-market issue. Therefore, there is a need for universities to provide such training to engineering students, and to assist them to think creatively when confronting current engineering problems and issues so that they are able to look at engineering problems in new ways [3, 4].

THE INNOVTECH FACILITY

The aim of the InnovTech facility within the City University of Hong Kong is to teach engineering students to become professional engineers with society in mind, and with creative and innovative flair. It consists of lectures on concepts of innovative and creative design, and case studies from industry which aim to demonstrate that creativity, innovation, responsibility, and professional ethics are important in actual working environments. Small group exercises are used to illustrate the principles of creative thinking and implementation. They are also used to create a scenario for managing change successfully and creatively.

Real cases from industry and field are also presented to students. In order to verify that students have understood, issues from industry are exposed to them selectively. These cases provide them room to experience creative problem solving processes, and to learn the right attitudes

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to handle different issues under various circumstances. As an old saying goes, 'practice makes perfect'; these innovative mind training activities stimulate students to think deeply.

The key focus of InnovTech is on creative problem-solving skills. Students are therefore introduced to creative problem solving-processes and creative idea generation techniques.

TOPICS

Creative problem-solving process and model

Many important inventions and new design ideas arise through the creative thinking process. As a matter of fact, this is the most natural and general approach to creative problem solving in many aspects, not just in invention and design. The aim of the creative problem-solving process is to make the engineer's work more efficient and more productive, so that more problems can be solved for the same expenditure of time and energy. Also, there are personal reasons for initiating a creative problem-solving process:

- Finding good solutions quickly frees up time to tend to other matters.
- Proficient and efficient problem-solving efforts help establish one's credibility with colleagues. Finding good solutions quickly is a time-honored way of establishing a reputation for general competence.
- If there is any job security left in the workplace at all, it is probably tied to one's ability to solve problems quickly and efficiently.

Many existing problem solving processes and models [5–7] are available. In order to employ a suitable model, students should understand the conceptual flow and realize that one should not be too dogmatic about when one step of the model ends and the next begins. The following introduces a useful model, developed by Fred Nickols [8], that students can understand easily. It is important to point out that the problem-solving model only **helps** students to solve new problems—it should not be followed rigidly and blindly.

The problem-solving 'bases' by Fred Nickols [8] are:

1. Define the problem
2. Specify the Solved State
3. Build Consensus and Support
4. Troubleshoot the Problem
5. Design a Solution
6. Identify the Means of Change
7. Settle on a Course of Action
8. Reconcile Restraints and Constraints
9. Prepare Plans and Schedules
10. Take Action
11. Assess Its Effects and Consequences
12. Adjust Future Actions

Creative idea generation techniques

To be the designer of an innovative product is an endless dream to most young engineers. It is not easy to become an innovative designer or engineer, but it is possible to review past experiences that can give us some clues about generating innovative ideas. Problem-solving techniques have been devised for every stage of problem solving from problem definition to solution implementation, however most are primarily intended for idea generation.

There are many well-known approaches and techniques [9–11] that can give students direction on how to generate and evaluate ideas effectively for creative problem solving. Basically, creative idea generation techniques are attempts to generalize the processes involved in certain aspects of creative thinking. These creative problem-solving techniques, however, have their limitations. They are based on theories of creativity and are useful in helping some individuals and groups to analyse problems and generate ideas, in design as well as in other fields. They provide guidelines to help an individual or a group formalize one or more of the intuitive or conventional approaches involved in creative thinking. Although they are often presented as rules to follow, the intention is that the techniques, once learned, should be used flexibly and adapted to the user's own thinking style.

Although there are many idea generation techniques, all work based on a limited number of principles:

- *Intuitive techniques* work by stimulating individuals or groups to come up with ideas spontaneously.
- *Systematic techniques* work by breaking the problem into parts, identifying known sub-solutions and then generating overall solutions by appropriate permutation and combination.

Table 1. Eight idea generation techniques within the matrix

	INTUITIVE	SYSTEMATIC
FREE ASSOCIATION	Brainstorming Brain writing Checklists Problem Reversal	Attribute listing
FORCED	Analogies	Morphological analysis Six Thinking Hat

Fig. 1. RCX in the ROBOLAB.

These two basic types themselves operate in two ways:

- *Free association* in which new ideas are stimulated in the mind arising from the experience, knowledge and environment of the individual and by ideas produced by other people.
- *Forced relationships* in which new ideas are produced in the mind by deliberately forcing together two or more established ideas that could be related or unrelated .

Combining these categories gives us four types of idea generation technique, as shown in Table 1.

The advantage of using creative idea generation techniques is to provide a situation in which a group of participants feel free to be imaginative and in which individuals learn new attitudes that help them to be more creative. Some designers have experienced that idea generation techniques are most useful when, through their use, one becomes able to generate alternative ideas.

PROJECTS

The projects follow lecture materials and examples presenting the concepts addressed by exercises similar to the following.

ROBOLAB is a powerful tool for the students from kindergarten to graduate school [12] to express their creativity since ROBOLAB gives unlimited space for the student's imagination, especially in Engineering and Science. ROBOLAB integrates the traditional Lego and a computer with electronic parts so that students can develop computer and engineering skills through hands-on experiences that relate to the real world.

The core of a ROBOLAB construction is the RCX which is shown in Fig. 1, a programmable LEGO brick that controls the action of the Lego model. The RCX contains 3 inputs and 3 outputs so that it can activate the output devices (e.g. motors, lamps, etc. shown in Fig. 2) when it receives signals from the different input sensors (e.g. touch sensors, temperature sensors, light sensors, and rotation sensors shown in Fig. 3). If students feel that the sensors are not sufficient for their development, they can build other types of sensor that meet their requirements. Commands, written in the ROBOLAB programming language, ROBOLAB 2.0 shown in Fig. 4, are sent to the RCX by infrared transmitter/receiver, allowing communication between the RCX and the PC.

In preparation for the project, students are divided into groups of four. First, they are taught about ROBOLAB, its accessories, and its programming. Then, they are required to select an appropriate creative idea generation technique to generate great ideas for their assigned projects, for example, a bumper car with sensors that can be used by a restaurant to serve meals to customers over a limited area, etc. They are then required to put all the creative and innovative ideas into action and build a workable model using ROBOLAB.

Finally, a presentation of their ideas and demonstration of their models are used as an assessment of their work. In a Robolab project, students not only think about the creative product in their project, but also they can share their creative

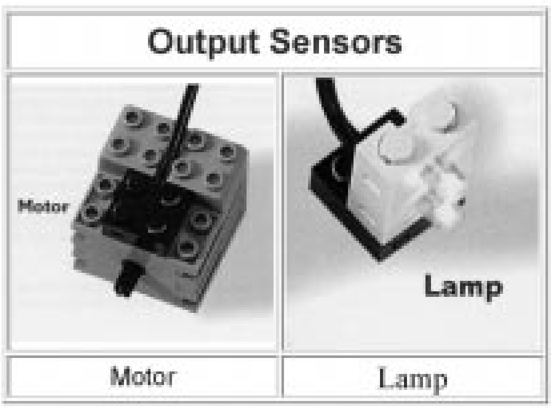

Fig. 2. Output sensors in the ROBOLAB.

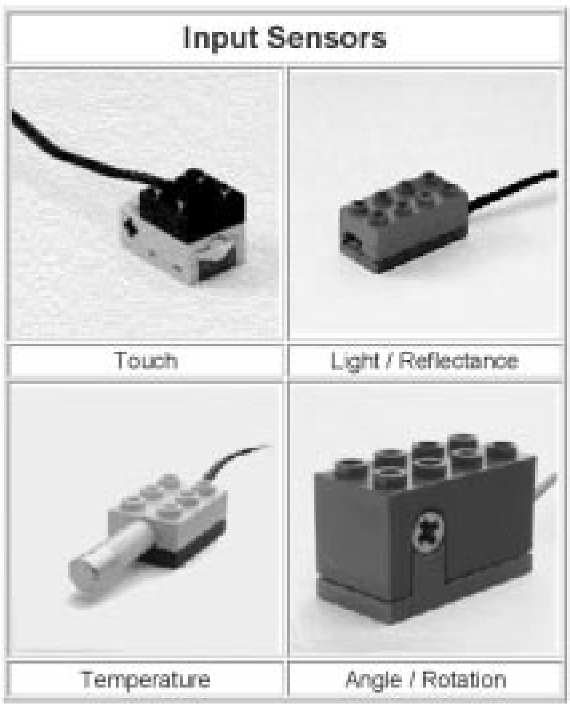

Fig. 3. Input sensors in the ROBOLAB.

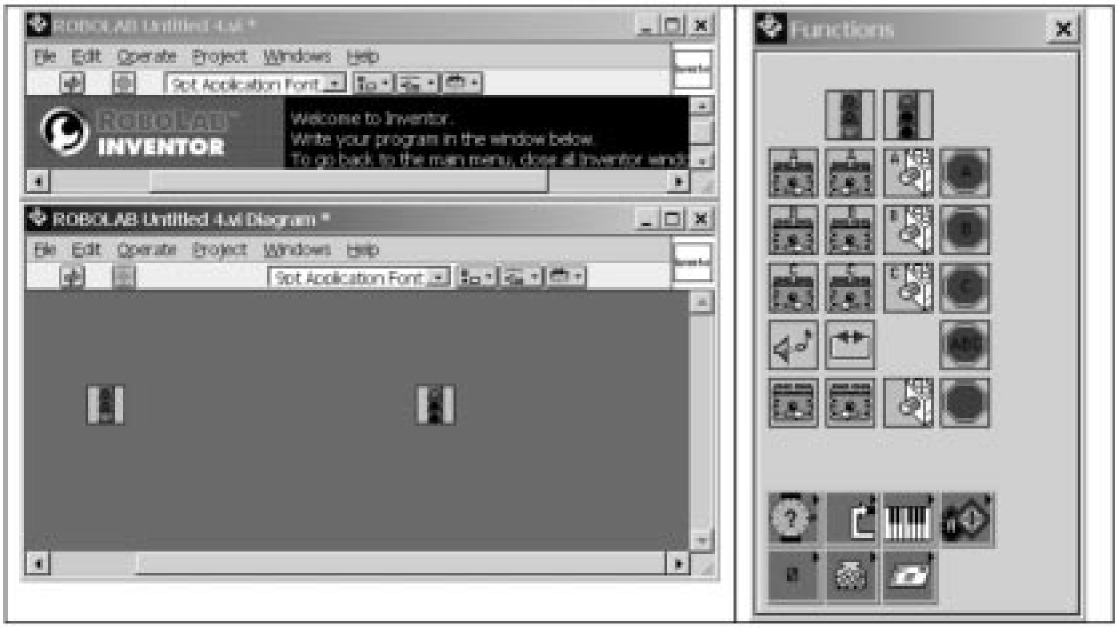

Fig. 4. ROBOLAB program, level 4 of inventor programming.

ideas and experience with each other by group discussion.

THE PROBLEM SOLVING PROCESS

These projects provide students room to experience creative problem-solving processes, and to learn appropriate attitudes to handle different issues under various conditions. In these exercises, a group of instructors are invited from the electronic packaging industry to simulate cases that meet the requirements of this project. These cases have been selected to allow students to practice the creative problem-solving process. In order to solve problems creatively, students should understand the problems and choose an appropriate technique.

Case studies from industry

An engineer working in manufacturing should have the right attitude, problem solving skills and, of course, knowledge in order to solve the numerous genuine and nagging issues. Getting it right first time is very important. Therefore, creative problem-solving skills and techniques are very much appreciated among engineers and managers. Many idea generation techniques have been introduced by experts, which most of them have been proven applicable and reliable. However, in order to achieve the aim of this coursework, i.e., to allow students to experience the creative problem-solving process using case studies from industry, the creative problem solving process has been simplified and collected into the following processes:

1. Understand the current situation
2. Define the goal and plan
3. Witness the occurrence of failure
4. Root cause analysis
5. Implementation
6. Verification

This approach is very powerful, especially for continuous improvement in chronic issues. Students were introduced to the front-end process in electronic packaging by the instructor. They were asked to improve a specific yield loss in industry by following these steps.

1. **Understand the current situation.** Raw data and overall yield reports were given, and students had to analyze the current situation by breaking down the overall yield. The aim of this action was to define the problem accurately. This stage involved ensuring that efforts were directed toward solving the real problem rather than merely eliminating symptoms. What would constitute evidence that the problem has been solved? The outcome of this stage was a set of decision criteria for evaluating various attempted solutions. The better the definition of the failure, the closer one is to dealing with the actual root cause.
2. **Define goal and plan.** When the problem is known, a goal should be easily identifiable. A goal should include a measurable improvement in a specific timeframe. All the team members had to agree with the goal, so everybody could work on it with full heart. Before getting started, the students were required to have a good plan or roadmap in order to reach certain milestones within a given timeframe.
3. **Witness the occurrence of loss/failure**. In this step, processes that were suspected to contribute to the identified failure were inspected until the failure was witnessed. This helped to narrow down the focus area to perform root

Table 2. A sample of a summary chart of observations

Process flow	Observation	Correlation (yes/no)

cause analysis and to gather clues, based on:
- sight
- hearing
- touch
- smell
- taste.

A summary chart of observations throughout the manufacturing process of interest should be presented. Table 2 shows the sample of a summary chart of observations and it can be modified based on the user requirement(s). The finer observations may lead to a better solution. Then, the short-listed processes that potentially contribute to the problem are singled-out for further analysis.

4. **Root cause analysis.** Several root cause analysis tools can be applied. In this case, 'Why-Why Analysis' was used—one continues to ask 'Why' until all observed phenomena can be explained. The 'OK' sign was placed at the end of a flow chart if it was found not to contribute to the problem or to be in good condition. Those items that were found not to be in good condition were highlighted by 'NG'. Therefore, counter measures had to be carried out within the given timeframe.
5. **Implementation.** Students were required to present their counter-measures to the root cause and convince the rest of the group. The implementation had to be logical and cost-effective. Students were also educated on the importance of convincing everybody with a good root cause analysis and a presentable proposal of counter-measures.
6. **Verification.** A Payntor chart was presented by each group to show the effectiveness of each counter-measure. Each counter-measure was responsible for certain reduction in yield loss, which together were required to eliminate the yield loss. Then, an implementation plan was presented to ensure all the counter-measures were implemented to all machines. This is used to standardize all machine conditions; thus it can prevent reoccurrence of the same failure mode in other machines.

DISCUSSION

The actual case from industry was carried out among the whole class. A new word has been introduced to students—'error-proof' which means eliminating the possibility of recurrence of that particular failure. Students were asked to come up with ideas for error-proofing that is mainly due to negligence of operators and technicians. For example, carriers are used in the packaging industry to transport bonded materials. However, due to absentmindedness and carelessness, the bonded materials are often not tightened properly, causing them to be mishandled. Therefore, the quality of such materials is not guaranteed.

It is very important to solve the problem by identifying the root cause using proper tools and then error-proofing it. In this case, the root cause has been identified as human carelessness. The idea generation techniques introduced in the 'lecture' are very powerful, and enabled students to came up with a creative magazine carrier design. They responded with great designs which were very creative and innovative, cheap, and, most importantly, able to error-proof the failure. When interviewed, most of them claimed that brainstorming was the most frequently used technique to generate the ideas, while checklist and attribute listing were also used by some of the students.

The InnovTech facility is designed for all final year students of the Faculty of Science and Engineering as part of the course titled 'Engineer for Society'. There are in total over 350 students i.e. part-time and full-time, in every academic year. The coursework covers 30% of the total marks. For the assessment, students are required to submit a report to describe their ideas and solutions. It should consist of a well-defined objective and problem description, and the whole problem-solving process that they have learnt from the series of lectures. Students will be given a chance to learn from each other by presenting their output at the end of the semester. Those outstanding reports and ideas will be shared online via the website of InnovTech: www.ee.cityu.edu.hk/~tdg.

InnovTech also provides the missing link between academic and industry in which experienced seniors from industry are invited to discuss engineering case studies and share their professional conduct and beliefs. This idea is slightly different from projects launched by other institutions [3, 4, 12], where InnovTech provides more exposures to the real industry cases and working environments. After two years of implementation, we found this project is beneficial as it has enhanced the competency of these students and employability.

CONCLUSIONS

Overall, the students' and instructors' experiences of creative and innovative learning via lectures and projects have been very positive. From their participation in the classes, the students have shown that they are very keen to become more creative and competent engineers. They enjoyed using the Innovtech facility and felt that employability was enhanced. They were taught to see each problem as an opportunity, rather than worry about it. *'Being creative is seeing the same thing as everybody else but thinking of something different'* [7]. This phrase has been repeated oftentimes during the exercises. Students were also taught to be professional engineers with the right attitudes and professional ethics, both in the classroom and outside.

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