TEACHING SCIENTIFIC THINKING TO STUDENTS OF INDUSTRIAL DESIGN

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ABSTRACT:

Design is the interplay between logical and holistic thinking modes. It is therefore important for students majored in industrial design to balance their right and left brain hemispheres for effective communications with technological people and proper handling of design procedures. However, the conventional science courses aimed at providing the students with scientific training have only marginal advantages; it seems that the content and activity in a conventional science course cannot effectively excite design students. In this study, we design a new course, *scientific thinking for designers*, as an introduction to subsequent technology courses in the department of industrial design at National United University (Taiwan). In the process of course development, some pilot surveys on our current students have been done for recognizing proper ways of training scientific thinking. As a one-semester course (3 hours per week), three domains consistent with the course spirit are selected: (1) information literacy; (2) mechanics; and (3) data acquisition, treatment and interpretation. The first domain will focus on building progressive

e-portfolios, which are a common element among many courses in our department. In the second domain, the students will learn logical deduction and basic concepts of mechanics, such as energy, momentum, force, acceleration, torque and rotational inertia, via action learning based on demonstration experiments designed and performed by students groups. In the third domain, the students will learn survey design and basic statistical analysis by treating real-life data that are collected from group projects. Given the limitation of teaching time, the content of scientific thinking can be flexible, but from our study the learning will be best facilitated by action-learning problems.

Keywords: industrial design, science education, action learning.

1. INTRODUCTION

Science, its knowledge and its way of thinking, is an important element in industrial design. Scientific thinking not only concerns the utility of a design product but also provides a significant mental boundary for industrial designers to work inside (Greenough 1962). Although challenged by other viewpoints (for example, Norman 2004; as reviewed by Michl 1995) in recent decades, the notion of "form follows function" is still widely taken by industrial designers. We therefore maintain that a solid training of utilizing scientific thinking is essential in the education for industrial designers. This paper is focused on an efficient way to train scientific thinking. This issue is becoming interesting due to recent changes in design education in Taiwan. Conventionally, students in a department of industrial design will go though a series of courses of basic and applied sciences in conjunction with their core design curriculum. However, in recent years, many programs in Taiwan have phased out basic science courses, such as Physics and Calculus, for two reasons. One is that the linkage between the basic courses to the core curriculum is not clear as viewed by the design teachers, and another is that the learning efficiency in those courses is not conspicuous. Consequently, more advanced technology courses have to yield to students with weak science background, becoming too simple to be significant. Turning back to reinstall the basic courses is not a good idea either, because the problem of low learning efficiency is left unsolved. In this study, we adopt a different philosophy, namely, using well-designed realistic problems to facilitate a form of action learning (Dick 1997, Garvin 2001, Zuber-Skerritt 2002) whereby students will be driven to learn and apply scientific concepts in solving the problems.. The topic course, *scientific thinking for designers*, is the first trial of this philosophy in our department.

As an introductory course, three topics related to industrial-design education are included, which are information literacy (Behrens 1994, TILT 2004), mechanics (a major part of physics) and statistics (and associated survey design). Collecting sufficient information of a product for design analysis is an important step in a design process, and the most convenient information source is the Internet, whose design news are generally provided in English. On the other hand, our incoming students are averagely weak in English. Therefore, the first capability training in the domain of information literacy is how to search for useful data on the Internet, which requires wisely using language-assisting tools. The second capability concerns expression, reflection and collaboration. The e-learning technique which is getting more and more attention is e-portfolio (Bloom & Bacon 1995, Porter & Cleland 1995, Barrett & Wilkerson 2004). The development of e-portfolios of progressive type for design education is regarded by our department as a common learning tool, because the students' design project can be evaluated by the process, not only the result.

In the physics session of this course, concepts of mechanics important to product design will be introduced. The following table shows the connections of some physical concepts to later design courses.

Concepts	Descriptions	Later Design Courses
force & motion	The causality of motion	A, B, C, D, E
torque & rotation	angular velocity & acceleration	A, B, E
momentum	Impulse; the conservation of momentum	A, D, E
energy	potential energy; kinetic energy; heat; the conservation of energy; heat conductivity & capacity of materials	C, D, D, E
stress & strain	elasticity of materials	A, D, E
center of gravity	gravitational force; rigid body	B, E
frictional effect	kinetic and static frictions	B, C, E
rotational inertia	Newton's second law of rotation	A, B, E
entropy	The second law of thermodynamics	C, E
A: ergonomics		
B: mechanism		
C: sustainable/green design		
D: product materials		
E: design engineering		

Table 1: important physical concepts in mechanics for design courses

Understanding the spectrum of people's opinions about an issue is another important design consideration. The third topic will focus on teaching the students to design a questionnaire in accordance with a distinct objective and to analyze the data thereby collected (Oppenheim 1999). The survey design will provide the students with an opportunity of understanding people in a scientific way and tackling available data for useful information.

In 2, we display the results from a pilot survey and deduce from the results the theoretical foundation of the science course reform. In 3, a new introductory science course for industrial-design students is elaborated. In 4, we summarize this study and discuss the future ideas for continuing this study.

2. PILOT STUDY

In the process of the course design, we have conducted some pilot surveys on randomly selected students in our department for gaining insight into the theoretical foundation on which the course will be developed.

The objective of the first survey is to recognize what sort of science/engineering education is needed and how it should be instructed. There are three major questions, (1) the engineering problems that bother the students the most in their design projects; (2) the way the students approach the solution to the problems; and (3) the activities the students think should be more stressed in a science/engineering course. These questions are multiple choices, and the students are required to list the priorities of their choices. The following table shows the result.

Question 1	the engineering problems that bother me the most in my design projects			
Sample #: 57	The three mostly cited problems	The problem selected the most as priority 1	The problem selected the most as priority 2	The problem selected the most as priority 3
	Mechanism* 3D computer graphics* Product Materials*	Mechanism	Product Materials	Mechanism
Question 2	the way I approach the solution			
Sample #: 57	The three mostly	The approach most	The approach most	The approach most

	cited approaches	often selected as priority 1	often selected as priority 2	often selected as priority 3
	searching the Internet asking the teacher asking students	searching the Internet	asking the teacher	asking the teacher
Question 3	the activities I think should be stressed in a science/engineering course for design students			
Sample #: 29	The three mostly cited activities	The activity most preferred as priority 1	The activity most preferred as priority 2	The activity most preferred as priority 3
	action learning** design-presentation training** collaborative learning**	action learning	design-presentation training	interaction between the teacher and the students after class
*The questions are actually asked more colloquially, Mechanism - understanding the coupling between the parts of a product; 3D computer graphics - presenting the 3D computer image of a product; and Materials of Product - selecting suitable materials for a product ** The questions are actually asked more colloquially, action learning – learning through solving realistic problems as group projects; design-presentation training – presenting design works effectively to others collaborative learning – providing a mechanism by which the students can learn from each other				

Table 2: the survey for recognizing what sort of science/engineering education the students need the most and how it should be instructed

It is found that understanding the coupling between the parts in a product (mechanism) and mastering 3D computer presentation are the technologies our students want to equip themselves with most frequently. However, they, with very high consensus, think that a science/technology course should incorporate the element of action learning (Dick 1997, Garvin 2001), whereby the students will learn knowledge through solving realistic problems together with their classmates. Meanwhile, the element of collaborative learning (Gokhale 1995, Dillenbourg 2002) is also underscored in this survey. Further, the most popular way for the students to find solutions to their respective design problems is the Internet. Combing these results, it indicates that the average students' learning profile is consistent with the concept of Web 2.0 (O'Reilly 2005), and we will take it seriously in designing the course, as will be elaborated later in the next section.

The objective of the second survey is to compare the preferences of thinking modes between the department of industrial design and two students groups of other disciplines at National United University. We use two popular online thinking-mode tests, those at http://www.web-us.com/brain/braindominance.htm and http://similarminds.com/brain.html , aimed at determining a tester's preference to right or left brain thinking modes (Hellige 1990). The purpose of this survey is to find the difference between the student groups and therefore justify the necessity of using a different teaching method for our design students. Since the essential point of this survey is to distinguish different students groups, the systematic error between these two tests is left untreated. The test results for each student are converted into a score between 0 (extremely right) and 1 (extremely left) and then averaged. Further, we remove the outcomes of the students whose two test scores differ by more than 0.2 (20%); therefore, the valid sample numbers are small. The following table is the survey result.

Group Type	Group 1: industrial-design students	Group 2: foreign-language students	Group 3: other engineering students
Sample Number*:	20	15	13
Mean:	0.610	0.608	0.615
Median:	0.609	0.576	0.627
Standard Deviation:	0.093	0.118	0.097
ANOVA test: The probability of assuming the null hypothesis (p-value under α=0.05)	0.9834		
* after deleting inconsistent samples			

Table 3: the survey of the preferences of thinking modes between different student groups

Although variations in means and standard deviations over the three groups can be observed, the differences are not statistically significant, because of the scarcity of samples. That is, based on the test result of ANOVA, we cannot reject the possibility that the populations corresponding to the three groups are actually indistinguishable. It implies that the students at our university are averagely the same in the thinking pattern by which they recognize knowledge. To interpret this similarity, we have to understand the method by which Taiwan's colleges select students. With no exception, the majority of our students are selected based on the scores of a national test of academic capabilities; such a standardized test is effectively a filter for kicking out students inclining toward the right-brain thinking mode. The foreign-language students at our

school are particularly selected from vocational high schools, and therefore they are generally not literature-oriented. This result does not suggest that the design students should share the same paradigm of science course. It suggests that the reason for the low learning efficiency in science courses is purely environmental.

The objective of the third survey is to test the students' preferences of lecture styles in scientific presentation. We prepare two movies, each lasting about 5 minutes, which elaborate the same concept of "rotational inertia" in two different ways. One is from deductive approach, developing the concept from the first principle (here, Newton's second law of motion) via rigorous logical deduction. The other is from inductive approach, specifying an experiment setup and its result and then reducing from the results the same concept. The students are separated into two groups, both doing the same test but with the movies broadcast in opposite orders; the responses from two groups do not show an effect of broadcast ordering. The students are required to view the movies and then answer two questions with respect to each of the movies. The questions are: (1) do you understand the concept?; and (2) do you like the presentation? The answers to the questions are ranged from 5 (very much) to 1 (not at all). The following table is the survey result.

Question 1	the degree of understanding the concept			
	deductive	2.77 ±1.180	inductive	2.79 ±1.048
Question 2	the degree of liking the presentation style in consideration			
	deductive	2.53 ±1.087	inductive	2.53 ±0.966
Correlations		Question 2 - deductive	Question 1 - inductive	
	Question 2 - inductive	0.599	0.429	
Number of Samples = 57				

Table 4: the survey of preferred presentation styles in a scientific lecture

Table 4 shows that: (1) the average learning effect by and preference toward those two movies are slightly about the 2.5 and almost the same. However, the amplitude of variation about the means is considerable, indicating that the students are polarized in their feelings toward two different presentation styles. Further, it is interesting to know that, based on correlation analysis,

the average attitude toward the movies is that if they like one, they will tend to like the other; if they dislike one, they will tend to dislike both. The result of the third survey implies that: (1) for our industrial-design students, their attitude toward conventional science/technology teaching is polarized, and the teaching method should be changed; (2) for our industrial-design students, the conventional science teaching styles, either inductive or deductive approaches, show little effect on improving the students' science/technology learning; and (3) therefore, improving the conventional lecture presentation is not effective.

3. Course Design

Before we go on to design the course, the results from the previous section are summarized to shed some light on the course development. The points deduced from the surveys are as follows.

(1) The students want a science/technology course emphasizing action learning (Dick 1997, Garvin, 2001) by which they can learn by tackling realistic problems and team work.

(2) Learning through the conventional lecture-style courses is inefficient, no matter given by deductive or inductive approaches.

(3) Our students averagely have similar thinking patterns to other Engineering students here.

If further confirmed in more rigorous studies, point (3) corrects a misconception that the students of industrial design students at our school are different in nature from other engineering students. In other engineering departments, the linkage of science/technology courses is explicit, and therefore the students are more likely to accept conventional lecture-style courses. On the contrary, the linkage between science/technology courses and the core design courses is implicit (but indeed substantial), since those design courses are project-oriented and dodging technology problems is possible. Therefore, the students are usually less enthusiastic toward their science/technology education. It is then natural for us to align the learning style of the science/technology courses with that of the core design curriculum. This reform concerns a paradigm shift in educational philosophy but is never novel (Knight 2004).

Considering these points and the operational definition of scientific-thinking education in the first

section, we propose the following syllabus for a new course, *scientific thinking for designers,* aimed at bridging the design courses and the science/technology courses in the industrial-design education.

3.1   General Ideas and Goals

a. Scientific thinking is a necessary mental element in a design process. This course will provide new design students a training platform for breeding basic science capability and knowledge which will facilitate subsequent professional courses. Since the department of industrial design at our school, along with many in Taiwan, has already phased out basic science courses, such as physics, chemistry and calculus, such a supplement is necessary. Further, the restoration of the conventional science courses will inevitably run into the problem of low learning efficiency, as disclosed by the surveys; we therefore think such an educational reform is significant.

b. The topics of this course will cover information literacy for designers, basic mechanics and survey design. The information literacy for designers is narrowly defined as: (1) the information skills of constructing a progressive e-portfolio for an action-learning group and a showcase e-portfolio for each student; and (2) the capability of searching the Internet for useful design information. The information literacy for designers thus defined is not limited to science education, of course; it is included in this course because effective use of IT tools and resources is an embodiment of efficient scientific thinking. The basics mechanics includes concepts in physics that are important to the students' later design projects and the subsequent technology courses, such as mechanism and ergonomics. The survey design will teach the students how to design a questionnaire in accordance with a survey objective and how to analyze the data thereby collected, which is of fundamental importance for collecting design ideas and marketing product. The survey design will provide the students with an opportunity of understanding people in a scientific way and tackling available data for useful information.

c. The concept of action learning should be the central dogma for the teacher to follow so as to really facilitate the learning. Well-designed action-learning problems will help the students learn the knowledge and capability training we want them to acquire. With action learning, the students will learn how to apply science knowledge to solve realistic problems and, more importantly, cooperate with other people to figure solutions.

3. 2   Activities

The following figures illustrate the processes of making a PBL (problem-based learning) problem and solving the problem; they are designed according to traditional procedures (Duch, Groh & Allen 2001, Delisle 1997, Lee 2001). Referring to Fig. 1 (a), before we write a problem, two questions have to be clarified: the background of the students and the knowledge to be taught. More specifically, since we would like to excite the students' will to solve the problem, the problem has to be interesting. In other words, it should fits the students' life experiences and should not be too difficult. Since a PBL problem is by definition ill-structured and open-ended, the teacher has to determine what the exact concepts and capabilities the students will develop during the problem solving; they should of course be compatible to the objectives of the course. Although the teacher will guide the students to search for new knowledge related to solving the problem, but it is inevitable that some information and concepts have to be provided at the beginning of a session. For example, if a problem session is about developing information literacy, the students have to know the meaning of this term in the first place. However, since the teacher's role in PBL is a learning facilitator, he or she has to make the necessary lecture as brief as possible. A written problem should be carefully checked so as to be consistent with the course goals. According to Fig. 1(a), there are at least 5 check points; a problem appears poor against any of the criteria will be revised.
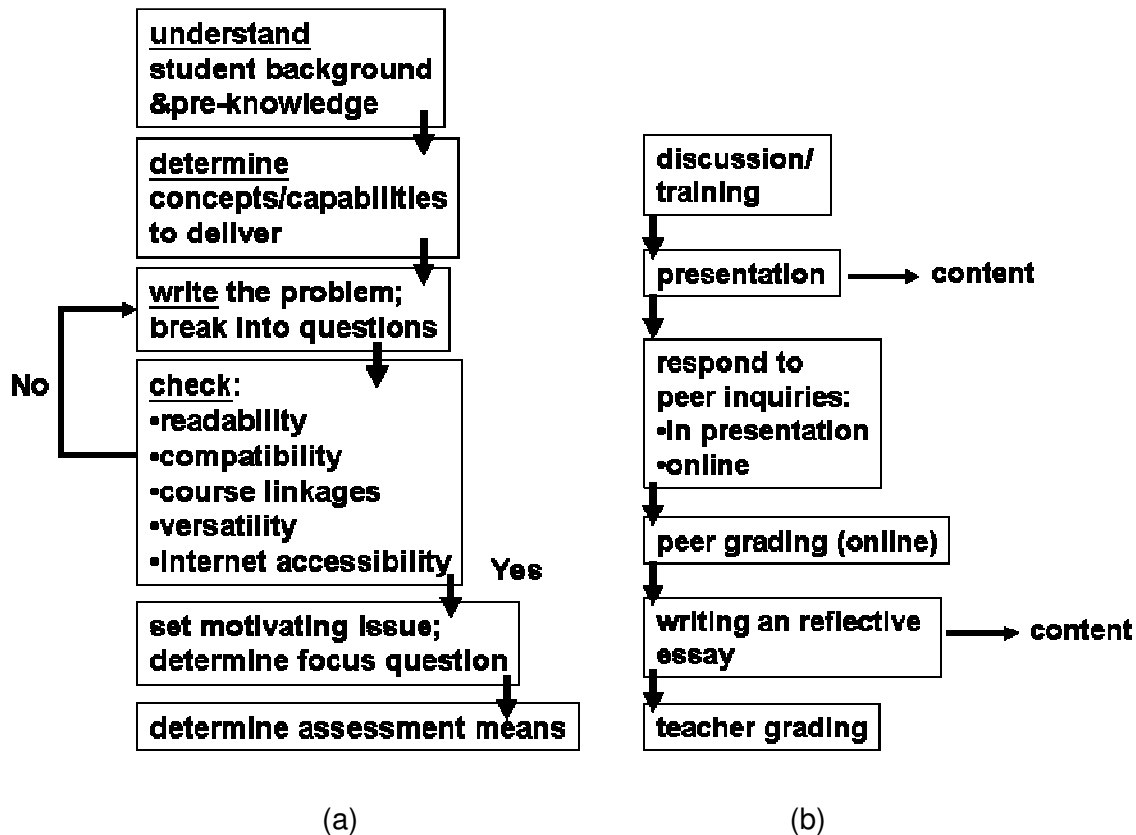
Figure 1: (a) the procedures of making a PBL problem; (b) the procedures for a student group to tackle a problem

The PBL (problem-based learning) learning is proceeded with the following steps:

a. Carefully designed problems are distributed to groups of 3-6 students. In the topic course, the problems cover the domains of information literacy, mechanics, statistics and sustainable design; the last concerns the application of the concepts of mechanics in a design project. For the problems of mechanics, the students are required to design experiments, and the teacher will provide them with necessary apparatus. For the problems of statistics, the students are required to design a questionnaire, to collect data, and to use MS Excel to perform basic statistical analysis. A group has to present their solution to the problem to the class, thereby other students sharing what they have learned in solving the problem. The students who are not presenting are obligated to ask questions and fill in the assessment form.

b. The content of a group presentation and the questions asked by the peer are required to be

published in the learning system. The group is obligated to answer those questions online, so that others can view their responses.

c. The peer assessment is done online and after the peer questions are answered. The assessment score will become a significant part of their final score.

d. The group has to write a reflective essay on how they solve the problem and what should be improved. This reflective essay will be graded by the teacher.

e. The teacher will encourage the students to publish learning outcomes of higher quality at their respective showcase portfolios, perhaps a personal blog. (We regard this is beneficial for promoting students' personal blogs, because the problems we have designed is modern and interesting.)

3.3　PBL problems

The following are brief descriptions of a few examples of the problem-based action-learning problems to be used in this course:

a. Information Literacy:

In a problem, the students are asked to visit three important design exhibition sites (iF, idea and red dot) to answer some questions designed to train their capabilities of information searching, organizing and analyzing information so as to create value-added information, and utilizing tools to decipher information in foreign languages. In the problem-solving process, the students are expected to learn the concepts of information literacy and value-added information.

b. Mechanics:

In a problem, the students are asked to design an experiment to elaborate the concept of the conservation of energy, perhaps using a track-cart system and a computerized measuring system. The students will be asked to search for information of the conservation law, to design a plausible demo experiment, and to illustrate the results on a computer screen. The conservation of energy is a pearl on the crown of physics. It is easy to use but sometimes difficult to understand, since the mathematical forms of various kinds of energy are artificially defined (What is the significance of a bunch of human-defined quantities cooperatively satisfying a conservation law?). Usual engineering students understand it through working out many computational

problems. We believe design students can understand this concept by actually designing an experiment.

c. Statistics:

In a problem, the students are asked to design a reasonably objective questionnaire for testing a psychological trait of the classmates and to do the associated statistical analysis to extract meaningful information from the data collected in the questionnaire survey. The students will learn how to deal with a large amount of figures by MS Excel. Further, the students will learn to interpret the result form the analysis and to draw conclusions.

d. Sustainability:

Based on the concepts of the conservation of energy and entropy, the students are asked to design shelters for mankind after the doomsday. The structures can be underground, under the sea, and orbiting the earth. The energy, air and food have to be self-sustaining for a long period of time. During the designing process, the students will have to practice the concepts of mechanics they have learned, and to develop a holistic scientific thinking.

3.4   Instruments

a. Experiment apparatus, coupled to sensors and computerized data acquisition devices, is supplied by the physics lab at our school.

b. The group progressive portfolios are built in the blackboard learning system at our school. Individual showcase portfolios are built by the students at their respective favored blog services on the Internet.

c. The tool of statistical analysis is provided by the teacher in the Excel format and therefore can be used in the students' personal computers.

4. SUMMARY

Pilot survey on the students majored in industrial design at our university implies that science/technology courses should be reoriented to problem-based action learning (Zuber-

Skerritt 2002, Dick, 1997, Duch, Groh & Allen 2001) so as to attain better learning efficiency. A science/technology course centered on solving realistic problems may be short of training of mathematics and overall understanding of a topic of science, but what is more important to design students is the utilization of science concepts in their design works. After balancing the utilization aspect against the completeness of training, we believe problem-based action learning is a better choice. The innovative course at our university thus designed, *scientific thinking for designers*, will be provided to new industrial design students in this fall. In this course, the students will learn scientific capabilities, such as information literacy, experiment and survey design, and knowledge, such as mechanics and statistics. The problems are designed according to standard procedures of PBL (problem-based learning; Delisle 1997, Lee 2001), as shown in Figure 1(a). To assure the quality of group interactions and peer assessment, the concept of progressive e-portfolio (Bloom & Bacon 1995, Porter & Cleland 1995, Barrett & Wilkerson 2004) is introduced, being facilitated by the university Blackboard learning system. The introduction of such an e-learning skill will further enhance the spirit of collaborative learning (Gokhale 1995, Dillenbourg 2002).

Our study is preliminary, and the course thereby designed is experimental; more rigorous investigation has to be done during and after the first trial. In a larger sense, we believe that introducing the concept of problem-based action learning (learning by doing) into science/technology courses for designers is significant, because this learning style emphasizes direct utilization of the otherwise very abstract knowledge of sciences. Further, learning by doing will simultaneously train some important lifelong learning capabilities, such as information literacy and survey design. Different from engineers, industrial designers rely more on creative problem solving than procedural knowledge, and therefore they need a fundamental training of scientific thinking, in which they may learn how to expand their knowledge domain efficiently. In the long run, well-designed and certificated PBL (problem-based learning) problems for design sciences and technologies can be organized to form a data base, forming a teaching resource for all courses in the department. Meanwhile, the history of doing the problems over various courses can be recorded in a portfolio for each student, based on which the department can evaluate a student's completeness of science/technology education.

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