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Introduction of Lateral Thinking to Civil and Environmental Engineering Education*

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Introducing lateral thinking to civil and environmental engineering students offers great potential to enrich students' creative and analytical capabilities. Engineering students are taught in well-defined and structured patterns and the academic discipline does not prepare students to deal with the unstructured problems of the real world. Lateral thinking enables students to escape the pattern and to devise multiple solutions to a problem. Specific case studies from civil and environmental engineering are presented to illustrate the use of lateral of thinking.

INTRODUCTION

THE CEEC 95 Civil Engineering Education Conference held in Denver, focused on four major components that need to be studied so as to improve the quality of education in civil engineering. These include technical competence, communication skills, management concepts, and team-work. It was realised that while engineering curricula are designed to address technical competence the other components are normally under-emphasised.

Most of today's educators started their profession with a global community that was viewed as distant and fragmented. Today, this concept is changing substantially due to the role information technology plays in our life. The Internet has shrunk the global community offering great potentials for increased productivity and teamwork. The International Union for the Conservation of Nature (IUCN), and its Commission on Education and Communication [1] reported that:

> 'Learning facts will be outmoded. Information technology will provide rapid access to a broad amount of information, soon providing access to those currently without free access'

However, the sizeable amount of information available requires that engineers need to exercise thinking to produce sound solutions. Interestingly enough, there is a trade-off between information and thinking. We need thinking in order to make the best use of information. However, if we have complete information this implies no thinking is needed. A crucial issue in engineering education is how to devote more effort and time to teach thinking rather than just data and information gathering. This is evident in the performance of many engineering students in their senior design project. Students are confronted with many problems when it comes to thinking about real-world problems. To overcome this shortcoming, Morris and LaBoube [2] documented the experience of the University of Missouri-Rolla in which they developed a senior design course that employs an effective teaching approach with faculty members who have both extensive teaching and industry/consulting experience.

Hence, to improve the quality of engineering education, we are confronted with these questions:

- What sort of information is needed to improve thinking and decision making?
- Shall we spend more effort on information gathering and synthesis or on thinking?

It is imperative that engineering students employ lateral thinking and escape some historical patterns and modes of thinking. However, in teaching engineering courses, students are mostly exposed to structured and well-defined problems; i.e., both dependent and independent variables are defined, and the students are evaluated on their ability to solve such problems. This is not relevant to what 'real' problems involve in terms of defining the extent of the problem, the users, and the linkages to other disciplines.

Limited deliberate efforts are focused on enhancing the student's lateral thinking and broadening the spectrum of possible 'solutions' to a single problem. Most engineering curricula are very effective in graduating very specialised engineers but with not enough skills in thinking and systems-oriented problem solving.

A new paradigm for civil and environmental engineering education is needed to cope with the two basic outcomes of information technology, i.e., diverse, fragmented, and sizeable information and interdisciplinary communication. This paradigm is characterised by focusing on system-oriented approaches in problem solving, team-work, communication, and lateral thinking as shown in Fig. 1. Interdisciplinary research

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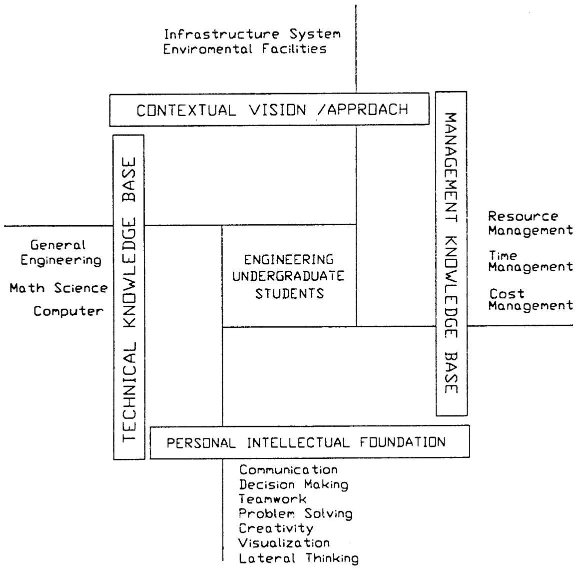

Fig. 1. A new paradigm in engineering education.

programs in engineering help reinforce the use and application of this paradigm.

This article was inspired by a course in research methodology and thinking developed for senior engineering students at the Applied Science University, Amman, Jordan. This course has been taught for the last five years. It is a three-credit-hour semester system and one of the general engineering college required courses. The course is presented in a seminar-like format. Small groups (three to five) of each engineering discipline are arranged to solve specific case studies. The course was graded out of 100.

The role of the instructor is a facilitator, the students are expected to define problems, collect needed data, devise sound methodology, and present alternative solutions. Both in-class and home assignments are given to students. The time of each class lecture is divided into three equal parts. In first part, the instructor introduces background, conceptual framework, and rationale of the problem in the case study. In the second part, the students are given about one-third of the class time to think, decompose, and analyse the problem. The third portion of the class is devoted for students to present their solutions. This part is normally followed by lessons learned, comments on modes of thinking, and paradigm shifts.

This article aims to shed some light on the use of lateral thinking in civil and environmental engineering education using a case study approach. It presents three case studies in the fields of transportation, water, and environment.

WHAT IS LATERAL THINKING?

Lateral thinking may be defined as pattern switching within a patterning system. Lateral thinking has to do with change of accepted patterns, modes, and/or dimensions of thinking

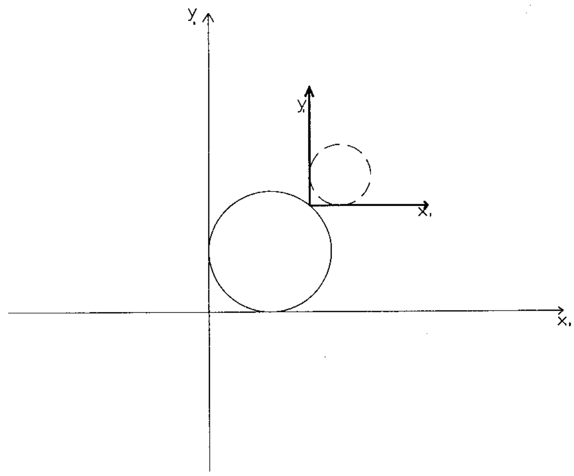

Fig. 2. Pattern change in lateral thinking.

as shown in Fig. 2. It may be viewed as a process of pattern changing and the ability to look at things in different ways. In other words, lateral thinking is both an attitude of mind and also a number of defined methods. The attitude of mind involves the willingness to try to look at things in different ways. It involves an understanding of how the mind uses patterns and the need to escape from an established pattern in order to switch into a better one. Lateral thinking involves low-probability ideas, which are likely to occur in the normal course of events.

Mechanisms used in pattern changing may include mistake, accident, random stimulation, and humour. In medicine some major discoveries were realised through accident, chance or mistake. It is difficult to see what other mechanisms exist for pattern changing. However, we realise that working with existing patterns will not lead to new patterns.

The rationale of lateral thinking is that many problems require a different perspective to solve successfully. The concept of lateral thinking is highly relevant to the concept of creativity. DeBono identified four different factors associated with lateral thinking. These include:

1. Recognising dominant ideas that characterise perception of a problem.
2. Searching for different ways of looking at things.
3. Relaxation of rigid control of patterned thinking.
4. Use of pattern change mechanisms; such as, random stimulation, chance, and brain storming to encourage the generation of new ideas.

DeBono has written extensively about the process of lateral thinking and the generation of novel solutions to problems. Debono [3] introduced concepts for use of lateral thinking in the generation of new ideas. DeBono [4] addressed the mechanism of mind as a means to understand the functions and processes within human mind.

DeBono [5] presented the application of lateral thinking to management development. Moreover, DeBono [6, 7] addressed teaching thinking to children.

New mechanisms for pattern change were described by Debono [8]. He commented that humour is probably the most significant characteristic of the human mind. It tells us much more about how the system works than does anything else. Humour involves the escape from one pattern and switching into another. In humour the double meaning of a word is used as the pattern-switching device to force us along the side- track.

Intelligent people, a characteristic of engineers, tend to be conformists. They learn the rules of the game and make the use of them to have a comfortable life. However, creativity usually is a product of not abiding by the rules. Engineering education, and early childhood education, should be developed to address creative and lateral thinking.

CASE STUDIES

The use of case studies in teaching some engineering courses proved to be of value. Grigg [9] documented his experience in teaching water resources management using case studies. He stated that programs that use case studies increase experience-based problem-solving techniques and integrate material from relevant discipline areas.

The methodology adopted in the application of case studies is based on both formal and informal teaching. The role of the instructor is a facilitator who presents to the students the conceptual framework of the problem. Students are grouped into small groups of three to five. They are given enough time in class to think and analyse the problem. Students' presentations are followed by comments on the use of lateral thinking. The implementation of lateral thinking through case studies is achieved through the following:

1. The instructor only presents a background and an overview about each case study. Each case study is decomposed into different elements; such as, 'users', 'needs', and 'constraints'. The instructor role in all steps is a facilitator. He does not need to provide significant input to help students generate solutions.
2. Through brainstorming, all possible 'patterned' or 'vertical' solutions are sorted out. Specifically, the students are asked to develop a list of possible solutions which are typical within each discipline. For example, if we have a traffic congestion at a highway; civil engineers are likely to give standard solutions. These include: (1) change traffic signal, (2) choose a different route, (3) Add more lanes or build an interchange. An attempt to develop a comprehensive list of 'vertical solutions' is made in this step.
3. The instructor utilises random stimulation and provocation to urge students to 'escape' and challenge the pattern and to develop a list of possible lateral solutions for each case study.
4. Analysis of the various lateral solutions are presented and evaluated. Specific reference is made for each solution and how it escaped the pattern. This is achieved by utilising the decomposed elements (in step 1), to construct simple forms of cognitive mapping.

The following are some case studies used for introducing lateral thinking to engineering students using the above methodology. The case studies are described for the general reader in some detail to shed some light on the settings of the problem. However, these case studies are presented to students in a much simple and synthesised manner.

CASE 1: TRANSPORTATION PROBLEM IN CHICAGO

This case study presents a transportation problem in Chicago City. Trends in transportation in the US were documented by Wachs [10]. He reported that since the end of the Second World War, there has been an enormous shift of employment to the suburbs. While we used to think of cities as centres of employment surrounded primarily by residential suburbs, since 1950 each census has shown that jobs have been shifting to the suburbs at a faster rate than residences. While commute trips entirely within the central city grew by 9% in the last two decades, commute trips entirely within the suburbs grew by 58%.

Due to economic growth and changes in travellers' patterns of preference, travel time and distance between 'Home' and 'Work' increased substantially. People who moved to suburbs, where they enjoy a better environment and more home space, have to commute to their workplace which is normally concentrated in downtown or the Central Business District (CBD).

In recent years, there has been increasing calls to include travellers' behaviour in transportation plans. Transportation Demand Management (TDM) is increasingly being incorporated into regional transportation plans, and the recent Clean Air Act amendments require employee travel modification programs. Moreover, the US Department of Transportation policy paper [11] recommended that transportation systems should be market-driven and responsive to changing demographic and travel patterns.

The problem arises as a result of two factors: First, commuters are discouraged to use their own cars due to both traffic congestion and because of the high parking cost in CBD (or trip destination). Second, commuters who choose to use the public transit have the disincentive of lack of sufficient parking space at the train station (or trip origin).

Hence, commuters have to take the bus to the train station and then transfer to the train to reach their destination. In other words, the problem is how to maximise the use of public transit and at the same time abide by the regulations of the Clean Air Act.

This problem is presented to students as a case study summarised in a schematic drawing. All components of the problem are identified. These include the driver, the road, the environment, and the vehicle. Students are arranged into small groups. Each group represents different engineering field; i.e., civil, architecture, mechanical, and electrical engineering. Students are asked to develop and generate possible solutions to the above problem using both vertical and lateral modes of thinking. Table 1 shows a list of vertical solutions developed by students for the transportation problem in Chicago.

The alternative solutions are classified by students as vertical or conventional solutions. Students are urged to come up with another set of lateral solutions. When students were confronted by the constraints of all the above solutions, some were able to develop and generate more solutions in a lateral mode. One of these solutions was simply to work at home on well-defined tasks. Employees can work at home for some days per week and report to their supervisors through electronic mail.

Discussions and comments were made on how and why some students' were able to escape the pattern and think in a lateral way. Rather than addressing the problem in a conventional or a vertical manner, as Table 1 shows, the lateral solution challenged the conventional notion of commuting to work place every day and utilised the information technology to accomplish some work tasks at home.

In an attempt to analyse the students' responses, it was found out that lateral solutions may cross disciplines of knowledge. In this case, information technology, computer and communication engineering were utilised to solve a civil engineering problem.

Most students' responses were typical or standard solutions, since in civil and environmental engineering curricula, emphasis is made on structured and uni-disciplinary education. Linkages between disciplines are not highlighted. Moreover, the pattern of commuting to work and parking at a transit station, was challenged and escaped by looking at the problem from a different perspective. By considering the lateral solution, working at home, we are re-engineering the transportation system.

Table 1. Students' responses to transportation problem

Solutions	Constraints
1. Build multi-storey parking garages	High cost
2. Encourage car-pooling	Flexibility of time
3. Enhance shared parking	Limited utilisation
4. Improve bicycle access	Limited utilisation
5. Develop transportation management systems (staggered work hours).	Flexibility of time

CASE 2: WATER PROBLEM IN JORDAN: SUPPLY VERSUS DEMAND

The second case study addresses the issue of 'future water crisis in Jordan' due to unsatisfied water demand. Jordan is characterised by an arid to semi-arid climate. Rainy seasons are short and annual rainfall intensities range from 600 mm in the northwest to less than 50 mm in the eastern and southern deserts, which form about 91% of the country's surface area. Jordan's (1995) population is approximately 4 million, and increasing at a yearly rate of 3.6%. Accordingly, the population of Jordan is estimated to reach 4.9 and 6.6 millions in the years 2000 and 2010, respectively. In 1993, Jordan consumed 983 million cubic meters (mcm) [12]. The contribution of surface water, ground water, and treated waste water amounted to 400, 533, and 50 mcm, respectively. Water consumption from all resources was 738, 214, and 33 mcm for agricultural, industrial, and municipal use, respectively.

Water demand is rapidly increasing due to increased development and the high rate of population increase. At the same time, water resource development constraints are increasing due to high investment cost and quality degradation. According to Murakami [13] by the beginning of the twenty first century, Jordan will have depleted virtually all of its renewable sources of fresh water, if current patterns of consumption are not radically altered as quickly as possible.

One conceptual problem in water management was described by Okun and Lauria [14]:

> 'The traditional approach to water supply, whether for community or agricultural use, is to estimate demands and to assume that the resource is available for the taking.'

During the past three decades, the development of water resources in Jordan has been largely limited to building hydraulic structures in the public sectors and exploiting of groundwater in the private. These efforts were meant to increase agricultural production and to meet the demands of a growing population. Supply-side efforts never met the increasing demands, and the result was continuous water shortages. The shortage of water in the country is reaching crisis proportions, even though municipal and irrigation supplies are already rationed.

The growth in demand has led to the exhaustion of surface water and to the over-extraction of groundwater. By overdrawing its groundwater aquifers, Jordan is losing an irreplaceable supply, increasing water costs and lowering the water quality. During this 30-year period, Jordan has had no clear water policy that might have led to a sustainable solutions to the water problem given the constraints on resources.

Based on projections of water supply and demand, Jordan is likely to face a water crisis by 2010. The picture looks particularly bleak where supplies for municipal purposes may not be secure. Careful measures should be taken now to set a balance between supplies and demands. In the past, different strategies were adopted to overcome the deficit between supply and demand, but these strategies would never attain their goal.

Generally, to reduce the gap between supply and demand, there are two basic solutions: increasing the supply and decreasing the demand. There are few options to increase the non-conventional water resources, which are looked at as supplements to, but not substitutes for conventional water supply. These options include: irrigation with saline water, desalination of brackish or sea water, reuse of treated municipal waste water, rain-water harvesting, cloud seeding, and importing water across boundaries.

When this background was presented to engineering students, most students proposed supply-side solutions to the water problem in Jordan, which include:

- Construct more dams
- Develop groundwater resources
- Desalinate water
- Import water

On the other hand, few students were able to consider the demand-side of water management. These include measures that affect the behaviour of consumers; such as, water pricing, public awareness, and efficiency enhancement. Discussions of the strengths and weaknesses of each of the supply and demand water measures to alleviate the water crisis in Jordan are presented

It is evident that applying effective demand management measures will help conserve water. As documented by the World Bank [15, 16], price distortions in particular often magnify both scarcity and water quality problems. Low water charges encourage consumption and waste. However, when good quality water is plentiful and cheap, it does not pay to invest in costly monitoring devices and pricing systems. Appeals to the public through public awareness campaigns, education programs, and similar initiatives have also led to significant changes in human behaviour related to water consumption and use, notably in developed countries Reduction in water losses is important to any demand management program. Unaccounted-for-water reaches as high as 50 to 60 percent in urban delivery systems.

The analysis of students' responses reveal that engineering students consider 'structural' solutions; i.e, to built, to construct, to drill. This is evident from the focus on engineering curricula on design and construction of structures with lack of systems engineering courses. Hence, the civil engineer views his future role as a 'builder' and in turn his proposed solutions are likely to be 'structural' with a focus on the supply-side of the problem.

The introduction of lateral thinking to engineering students enable them to escape the conventional pattern and to look at the water problem from a different perspective. Shifting focus from 'supply-side' to 'demand-side' in the water problem offers a wide and different array of solutions. It simply presents a new vision to water in arid countries.

To induce lateral thinking solutions through a case-study approach, a communicative approach in problem solving was utilised. Willingness to try and explore possible solutions are highly encouraged. The interaction of students in the process and the responses received were very encouraging.

CASE 3: GLOBAL ENVIRONMENTAL ISSUES

The issue of global environmental problems; such as, acid rain, global warming, and ozone depletion are currently of significant importance. The two major challenges for experts in this field are to study the extent and complexity of the problem and to devise effective solutions. This case study addresses possible solutions to ozone depletion and global warming.

Ozone depletion and global warming currently enjoy a much higher profile than other global environmental issues. They are the focus of research aiming at identifying causes and effects of the problems. The issue of ozone depletion has reached decision-making stage, whereas in the study of the global warming the technical aspects of the issue; such as the definition of extent and timing, continue to receive much of the attention.

The Vienna Convention on the Protection of the Ozone Layer, which emerged from a 1985 conference, was followed in 1987 by the Montreal Protocol. In the Protocol, agreement was made to reduce production of chloroflurocarbons (CFCs) by 50 per cent of the 1986 values by the year 2000. In 1989, the members of the European Community agreed to eliminate production and use of ozone-destroying chemicals by the end of the century. Like ozone depletion, global warming has been the subject of a large number of conferences. In the 1992 earth summit at Rio, global warming was considered as a major element in the broader study of global change. As a result, an annotated bibliography of several hundred publications was published on the topic [17]. As the investigation of the global warming enters the decision-making phase, possible solutions are being investigated.

After this background was presented to students, they were asked to generate possible solutions for the global environmental crisis using lateral thinking. The solutions presented by each group vary in terms of scope, timeframe, and rationale.

The students' responses may be grouped under two broad categories. First, economic incentives and sanctions and second, changing people's consumption patterns.

The first category is characterised as a market-oriented solution (and vertical thinking mode) to the global environmental problem. This category of responses proposes fiscal measures such as taxation. This notion is based on the concept of 'polluter pays'. For example, a carbon tax, paid on fuel consumption has been suggested as a means to reducing fuel use. Moreover, the resulting higher fuel prices would in theory lead to improved energy efficiency. The revenue generated by the tax could be used to offset existing environmental damage created by fossil fuel use, or invested in environmental research.

On the other hand, the second group of responses may be described as lateral thinking solutions. They propose both adaptation and changing consumption patterns and lifestyles in order to mitigate global environmental issues. The rationale is based on another model which is 'prevention pays'. For example, people can minimise the negative impact of environmental problems by spending less time in the sun. Another way to limit these problems is through energy consumption. Improved energy efficiency, for example, would have a remarkable contribution in creating a cleaner atmosphere. It would reduce the output of CO_2 and CH_4, the main 'greenhouse' gases; it would bring about a decline in atmospheric acidity by reducing emissions of SO_2 and Nox.

The responses of students were distributed among both vertical and lateral modes of thinking. As more cases are presented to students, it is interesting to see that they are able to escape patterned modes of thinking and to look at problems in a broader view. Hence, they were able to develop more lateral solutions.

CONCLUSIONS

Introducing lateral thinking to engineering curriculum proved to stimulate engineers to think in a much broader perspective and to generate non-conventional solutions to complex engineering problems. In a world of limited resources, this mode of thinking is likely to produce cost-effective solutions and improve the quality of problem solving in engineering.

Teaching lateral thinking through case studies proved to be fruitful and insightful. Engineering students became more exposed to real-world and unstructured problems. They were able to provide solutions that are sound and feasible economically, socially and politically. Combination of both 'vertical' and 'lateral' modes of thinking is likely to offer new solutions to engineering problems.

A new paradigm in engineering education is needed which is characterised by focusing on systems-oriented approaches in problem solving, teamwork, communication, and lateral thinking. Interdisciplinary research programs in engineering help reinforce the use of this paradigm.

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