

Weaving Innovation into the Fabric of Engineering Education*

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Generating wealth requires new ideas that find a path to market. In order to produce new ideas it is important to equip university graduates with creative thinking tools and an innovative mindset. This article chronicles the authors' quest to provide such an education to business and engineering students and suggests principles that could be used to replicate the experience.

INTRODUCTION

IT HAS long been known that innovation leads to the creation of wealth in a process referred to as creative destruction [1]. In fact, according to a recent survey, half of the US economy's current growth comes from companies that didn't exist 10 years ago [2]. Moreover, the vast majority of these companies are small to medium size businesses. In Canada there is a perceived innovation imperative and the federal government has rolled out an innovation strategy that articulates objectives for learning at post secondary institutions [3, 4]. It is with this as a backdrop that the authors have attempted to enhance the innovative output of their students through training in creative problem solving.

For purposes of this article creativity is defined as *the generation of new ideas* that include the two hallmarks of *novelty* and *appropriateness* [5] while innovation is defined as *the process of taking new ideas to market* [6]. With innovation and creativity taking such an important role in growth and job creation, it is incumbent upon universities to impart a creative thinking skill set to graduates. This article presents the joint experience of two faculty members at Dalhousie University, one from the School of Engineering, Tim Little, and the other from the Faculty of Management, Ed Leach. The authors will share their experiences and then reflect on the process with the intention of finding replicable principles.

BACKGROUND

Each of the two authors had independently observed the need for their students to be more creative in their thinking. In the Engineering

School a number of open-ended and design type problems had been incorporated to address the need, but it was clear that not enough creativity training was being done. Work with Entrepreneurship students found that first-year students, in general, were far more creative than senior students. For example, in a mini-venture assignment (start a business for a week with a maximum investment of ONE dollar), several first-year projects earned over \$1,500 profit with one project earning \$12,000. In comparison, more senior students rarely exceeded \$500 in sales, let alone profits [7]. There was a concern with the creative potential of these students and it seemed the problem was exacerbated as they proceeded with their education. Something had to be done.

Tests with engineering students at McMaster University [8] and with business school students at the University of Texas [9] suggest that creative potential can be enhanced over the duration of a degree program with appropriate intervention. In an attempt to maintain the creative energy of first-year students, the authors agreed that creativity enhancement would help in all of their classes. Lecture materials were developed that emphasized creativity and outlined the basic creative thinking techniques. The two have worked together using this approach for about five years for a number of different audiences (including entrepreneurship, management, new venture, engineering and several non-academic settings such as toastmasters). The lecture format has always been a story-telling style in which the audience is engaged by creating a scenario they can see themselves in, and once engaged, are able to discover their own solutions for the challenges they face [10].

The authors based their delivery approach on the two-dimensional matrix (knowledge versus cognitive process) represented in Fig. 1 [11]. It was recognized that students would need to move into the conceptual, procedural, and meta-cognitive knowledge areas in order to analyze, evaluate and create commercial opportunities.

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	1. Remember	2. Understand	3. Apply	4. Analyze	5. Evaluate	6. Create
A. Factual						
B. Conceptual						
C. Procedural						
D. Meta Cognitive						

Fig. 1. Bloom's Taxonomy revised[11] (now a two-dimensional taxonomy that locates creation as a higher-order cognitive process).

Meta-cognition is defined as knowledge of cognition in general as well as awareness and knowledge about one's own cognition and includes:

- strategic knowledge;
- knowledge about cognitive tasks;
- self-knowledge.

The creative process puts elements together to form a functional whole or reorganizes elements into a new pattern or structure and includes [11]:

- the sub-processes of generating explanations of an observed phenomenon;
- planning or devising a procedure for accomplishing a task;
- producing or inventing a product/service.

The authors believe that the use of authentic learning contexts, which were of personal interest to the students, aided in the conversion of inert knowledge to knowledge owned by the learner.

INSTRUCTIONAL CONTENT

Content given to the students provides a framework for their creative thinking. Common pitfalls are introduced in a fun, non-threatening format and are followed by structured tools to open the students to new possibilities and opportunities. During delivery of the materials we work on reinforcing the concept that creativity is not giftedness nor surprise but something that they can accomplish and grow into. The Kirton Adaption Innovation Inventory (KAI), is used to illustrate that some people prefer an adaptive style to being creative while others prefer an innovative style [12] and to reinforce this notion it is pointed out that the majority of new patents are issued as improvements to existing patents [13]. In helping the students to structure their thinking skills, emphasis is placed on Plesek's three constructs: attention, escape and movement [14]. Our approach fits that analysis in that we spend significant class time

on defining the problem (attention), challenging the assumptions (escape) and generating alternatives (movement).

Novice problem solvers often jump to the solution implementation stage without carefully defining the problem they are trying to solve [15, 16]. To illustrate these problem definition ideas, we use an object which is depicted in Fig. 2. The block is made out of two pieces of wood, which separate easily. On first glance it looks impossible to separate because of the dovetailed edges. Pushing or pulling along any of the six facets clearly does not work. The cut of the block makes people think along the x-y-z planes whereas the solution requires them to push on the corner as the block is assembled on a diagonal axis. This is used to illustrate that it is usually someone else who defines the problems we work on. In such circumstances our vision of the problem, hence solution alternatives, will be constrained by the vision of those who have defined the problem.

The second key to creative problem solving is to challenge the assumptions. Assumptions are often made because of current experience or technology. As new methods and technologies are developed old assumptions may not need to be discarded but definitely need to be challenged. We often use a tool called 'Why A B C' which Edward de Bono has developed to reinforce the need for challenging assumptions [17]. Students are reminded of how the Internet has changed the way business is conducted and that most underlying assumptions need to be revisited with every new generation of technological change.

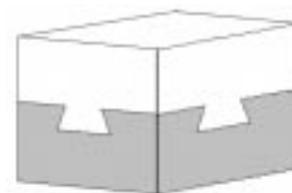


Fig. 2. Tool for problem definition clarification (solutions often depend on the way the problem is presented).

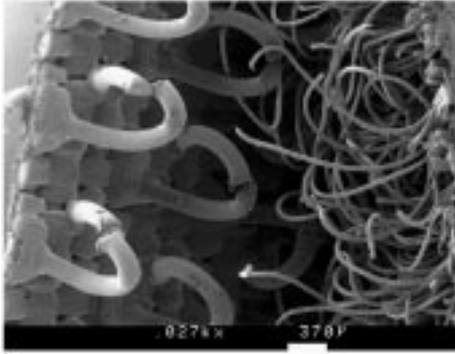


Fig. 3. Scanning electron image of Velcro [19] (used to illustrate principle of bionics).

The third is to talk about ways to generate alternatives, which include brainstorming, bionics and analogies. For example, students are given one minute to list all the uses they can think of for a ball. Typically each individual student is able to generate about five to ten different ideas with the odd person having as many as fifteen. As the ideas are compiled from the entire class as many as twenty to thirty ideas emerge. The students clearly see how the power of a group multiplies the idea potential and we as instructors suggest that it is important to assemble a group with diverse interests if novel ideas are to be generated [18]. Moreover this tool helps a discussion of flexibility and lateral thinking in the ideation stage. Through the mechanism of bionics students learn how natural solutions can result in technological solutions. The example of how burrs led to the invention of Velcro illustrates the principle (Fig. 3).

Finally we demonstrate the power of analogies for increasing thinking power. A solution in one realm may provide the seed for a similar solution in an analogous realm. For example, considering the way seeds are propagated may result in a new marketing strategy or a discussion of the similarities between chronic pain and terrorism may lead to new approaches in either realm.

All of this discussion is followed by repeated opportunities throughout the remainder of the term to apply the thinking skills and problem solving techniques (in new venture and entrepreneurship activities at the School of Business and in electrical design problems in the School of Engineering). It is here the students start to internalise the methods and apply them not only to academic work, but to personal and other non-course related problems.

DISCUSSION

Student feedback caused the authors to believe that something exciting was happening. In over forty years of combined teaching experience, the feedback had neither been so positive, nor so sustained. They repeatedly and in varied ways claimed that we had given them the permission

to think, as if for the first time! The students who participate in the creativity sessions seem to have an elevated level of self-efficacy in that they participate more readily, work harder and persist longer when they encounter difficulties [20, 21]. The instructional design literature identifies three effective learner characteristics that, in the authors' experience, are impacted by the presentations [22]. Participants:

- view the training as fun and relevant (attitude toward learning);
- have an enhanced sense that they can learn to be creative if they choose to (academic self-concept);
- seem to feel that the responsibility for being creative rests within themselves (attribution of success).

In presenting our material we observed that in order to solve real problems in a creative way, it is necessary to have in-depth knowledge in the domain of interest. However, having in-depth knowledge in one area often constrains the thinking to a particular style of solution, which limits creativity [23]. One must consciously break out of the mould [24]. *Patterns* cue experts as they make diagnoses and solve problems, based on partial or incomplete information. Experts are able to see a pattern and intuit that this problem is just like . . . Yet these same patterns can lead to faulty or less than optimal solutions as the problem solver uses prior solutions to solve today's problems. It is the ability to correctly use these cues that discriminates novice creative problem solvers from expert creative problem solvers [25]. Positive connections between creative problem solving and opportunity finding have been identified in the entrepreneurship literature [26–30].

Students reported overwhelmingly that it was critical that the material be delivered in a high-energy, fun way. Samples of student feedback are included below:

- 'I realized everyone, including me, has some creativity.'
- 'Personally I feel that through my education I have become less creative in my problem solving abilities and as I am getting ready to graduate this type of course/ability could give me a competitive advantage when starting a new job.'
- 'I will continue to expand my way of thinking and will be able to let more of my creativity out.'
- 'I realized that the only thing stopping people from being creative is themselves.'
- 'I will no longer let fear of failure stand in the way of creating ideas or acting on them.'
- 'I was given permission to THINK!'
- 'Previously I thought I'm not a creative person at all, in any sense of the word. Now I have come to realise that I am very creative in the adaptive sense.'

The authors hold the opinion that the high-energy delivery is integral to the empowering

process. It is our observation that this approach to creativity training has resulted in a significant enabling of our students and will result in a long-term benefit to them and to society as a whole. We believe that others who follow a similar approach will also experience similar benefits.

Differences between the two schools

The two authors have noted the impact of their efforts has been more pronounced in the Faculty of Management than in the School of Engineering. This is partially explained by the fact that engineering accreditation requirements leave little room for exploration beyond core topics while in the Faculty of Management business plans serve as the term projects. Value propositions, market segmentation and paths to market are integral to success in the management course. An effort is made to create authentic learning contexts where students pursue practical projects in which they have invested emotional equity. In contrast, the School of Engineering material has been used for isolated design project work but is not yet fully integrated.

Leach, the Management faculty member, is an entrepreneur and is able to speak directly from past and current experience. Cases, texts and assignments actively model entrepreneurial behaviours. In management, extensive use is made of entrepreneurial practitioners as guest presenters while more limited use has been made of outside resources in engineering. In the management courses, marks have been used to validate that creativity and innovation were integral to the learning. As an example, the most recent mid-term required students to critically evaluate the innovation agenda of the government of Canada [3, 4]. Marks in engineering have traditionally been given for the quality of the overall projects and not specifically for the creative and innovative aspects, but this is changing. At the School of Engineering, creativity is being emphasised more in design courses and new courses introduce entrepreneurial aspects to engineering students. Specifically, Little is involved in a multi-university, multi-disciplinary entrepreneurship course for engineering students, which will be offered by distance in the Winter of 2004.

Some schools such as McMaster have been able to take area-wide approaches to augmenting curriculum [8]. In the authors' experience many others, including their home university, Dalhousie, must rely on the efforts of individual faculty members to act as innovation champions so that the language of innovation becomes part of the day-to-day experience of an engineering education.

CONCLUSION

Innovation implies the useful exploitation of ideas [31] but usefulness is rarely seen as a virtue in academic settings and is often characterized as unscholarly [32]. Little and Leach have been fighting a guerrilla action, acting as champions in their respective faculties. There is little reason to believe that the dissonance described by Taylor in accepting innovation (commercialization) as a core value will ease in the near future. Yet the first cracks have appeared in the institutional dyke. For example Canada's Innovation Strategy (www.innovationstrategy.gc.ca) is taking a comprehensive approach to creating an innovation culture in Canadian society at large and within institutions of higher education in particular. At Dalhousie, the Faculty of Engineering has a new centre, the Innovation in Design Lab, a new entrepreneurship program housed in the School of Computer Science, and a new interdisciplinary entrepreneurship program, the Entrepreneurial Skills Program (ESP) in the Faculty of Management. Assembly of critical mass has moved the innovation agenda forward more swiftly. The critical mass generated by the initiatives above has helped us move the innovation agenda forward.

The starting point was two faculty members from different disciplines who shared a common interest (creativity/innovation) serendipitously brought together and who chose to collaborate. Their ongoing interaction has supported the integration of innovation into the curriculum. Each university that embarks on this journey will develop programming that reflects the unique character of their faculty, students, research agenda and community. The recipe for introducing innovation instruction will be as varied as the individuals desiring it. However, this recipe will be likely to include:

- the need for individual faculty members to take ownership and champion the effort;
- the weaving of innovation into the fabric and core values of the learning;
- the leveraging of the effort through attachment to the institutional mission;
- active promotion of the virtues of the effort.

The authors have enjoyed the journey to date and believe that they have made a valuable contribution to engineering and management education at Dalhousie University. We encourage other universities to embark on their own innovation learning journey.

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