AC 2010-1609: IMPROVING INNOVATION BY ENHANCING CREATIVE CAPABILITIES IN ELECTRICAL AND COMPUTER ENGINEERING TECHNOLOGY STUDENTS

Jeffrey Richardson, Purdue University

Leslie Reed, Reed Environmental

Improving Innovation by Enhancing Creative Capabilities in Electrical and Computer Engineering Technology

Abstract

This project evolved from an existing research effort in electrical and computer engineering technology in which the gap between the creative capabilities students brought to bear when solving technological problems, and the level of creativity demonstrated in a capstone design project, was explored. The original study was largely exploratory and was designed to measure broad influences on creative behavior in a technological project management environment. Continuing that effort, the current project involved the development and implementation of a series of lectures and skill sessions designed to assist students in developing creative capabilities in an electrical and computer engineering technology project management course. The project was designed to assist students develop more innovative ideas for capstone design projects.

Introduction

The evolutionary and diffusive nature of modern technology suggests that most challenges, opportunities and problems in 21st century life will have strong technological components. A powerful tool for generating value in the global economy and capitalizing on rapid technological advancement is the process of innovation where creative ideas are put into action through the development, adoption and implementation of new or significantly improved ideas, goods, services, processes or practices that are useful in some way[1]. An organization with broadly distributed innovation capabilities, including tangible resources, such as financial and physical assets; intangible resources, such as brand and reputation; and human-based resources, such as knowledge, skills and capabilities, is well-positioned to meet the challenges of the 21st century business environment[2].

Creative capabilities, a subset of human resources, are defined for the purpose of the research as individual skills, abilities and behaviors necessary for an individual to participate in creative work in a given domain. Every individual has a preferred locus of creative work and brings to that work a unique set of creative capabilities and personal histories that influence their interaction with the innovation process[3]. The human element is the most powerful and elusive force in the process of innovation, and it is theorized that all individuals have the potential to be more creative; that creative capabilities can be supported through more focused, systematic and deliberate educational efforts; and that maximum benefit will be obtained if efforts to enhance creative capabilities are grounded in a given domain[4].

Technology educators must provide technology content knowledge and technical tool skills to prepare students for the highly technological job market. It is equally important, however, to provide students with the opportunity to learn adaptive and innovative approaches to problem solving in technology[5]. Creativity as an outcome is ultimately judged by the novelty, effectiveness, and elegance of the products generated and it is only through reference to these products that society labels ideas, processes and products as creative. The judgment of creativity

in a given domain is heavily influenced by its gatekeepers, including educators, professionals, journal editors, and leaders who maintain and promote organizational structures, practices, resources and cultural considerations that define and constrain creative work in a given domain. These constraints lead to instructional practices that reinforce positive characteristics valued by gatekeepers, yet accountability efforts by gatekeepers can encourage academic experiences that reinforce a conformist, algorithmic approach to learning that stifles individual creative effort[6].

Design as a problem-solving method can be, at times, straightforward, linear and algorithmic, while at other times it's complex, circular, iterative and creative. The design process in technology education programs, however, is often presented as an algorithmic problem-solving method, with a series of steps to be followed, though not necessarily in a specific order. There is increasing evidence, however, that innovative solutions do not arise in such a simplistic manner and that certain cognitive processes differentiate ordinary problem solving and inventive problem solving. The most innovative of design problems do not have precise starting or ending points and they are solved by a combination of strategies that come from memory, readily available knowledge, and strategies that have to be created. Innovation and invention are among the most open-ended and creative problem-solving approaches yet there are few examples of what behaviors and cognitive processes are unique to this type of problem. The capabilities required for acting, thinking and doing, i.e, the process components of design in invention and innovation, are somewhat ill-defined, such that all forms of design instruction are not of equal value in targeting skills at the innovative end of the technology spectrum[7].

One of the principle differences between the aesthetic creativity found in artistic forms and functional creativity required of technological forms is the requirement that the latter perform a task or solve a given problem. Technological innovations are first judged on issues relating to effectiveness, i.e. does the product solve the problem it was intended to solve within design constraints. Effectiveness takes priority over novelty and originality, though both must exist for a product to be considered creative. In artistic expression, novelty alone may define its aesthetic merit to society, where novelty of invention will only partially determine its value in the market. Novel ideas, processes, methods and techniques are at the root of the innovative process in technology and it's important, therefore, that educational programs cultivate not just knowledge and skills, but dispositions and attitudes of open-mindedness, curiosity, and risk-taking.

Background

Spanning the creative person, process and product, this study examined if the introduction of creativity enhancement tools resulted in more innovative approaches by students as they identify and solve problems in a project management course in electrical and computer engineering technology (ECET). The tools evolved from a dissertation research project in which an attempt was made to illuminate the gap between student creative capabilities, including insight, cognitive style, motivational orientation, personality traits and learning style, and performance on a capstone design project in ECET. The analysis of the preliminary data, coupled with findings from similar studies in related domains, were used to identify areas in which malleable aspects of student creative capability could be incorporated into the project management course for maximum impact. Educational units were developed to enhance aspects of creative performance

in technological innovation that, following pilot and field testing during the 2009/2010 school year, will be incorporated into the class.

An additional purpose of this project was to expand the content on innovation and entrepreneurship to the existing capstone course, ECET 39600, in an effort to add the course to the approved course list for the Certificate in Entrepreneurship and Innovation. The improved version of ECET 39600 would serve as an approved course selection under the capstone requirement for the Certificate in Entrepreneurship and Innovation. Students within the ECET department routinely enroll in courses already listed under the "option" courses as part of their normal plan of study. Example option courses include COM 31400 Advanced Presentation Speaking, CE 35500 Engineering Environmental Sustainability, and various EPICS courses. The two required courses: ENTR 20000 Introduction to Entrepreneurship and Innovation, and ENTR 20100 Marketing and Management for New Ventures, are already counted towards the graduation requirements on the ECET plan of study. Therefore, adding the capstone course to the list will make the Certificate in Entrepreneurship and Innovation obtainable by all students within the ECET department at Purdue University without adding any additional courses to the student's plan of study.

Course

The ECET 39600 Project Development and Management course is required for all students within the ECET department. The course provides a structured introduction to electronic projects, with an emphasis on planning and design alternatives to meet cost, performance, and user-interface goals. Students work in teams to solve problem assignments using guided design techniques. Creativity is stressed, and the different approaches taken by different teams are compared and discussed. All students participate in a team project, planned and carried out during the semester. The students then complete the planning phase of their individual capstone senior project, which is carried to completion in ECET 49600 and ECET 49700.

In this capstone course, the students are tasked with the conceptualization and initial development phases of an electronic device to accomplish a student defined task. The device must have some identifiable aspect (form, fit, or function) that is innovative. Despite the requirement for innovative approaches, students, in general, fail to deliver products that are judged to be truly or highly innovative at the completion of ECET 49700. Changes need to be made to address the shortcoming of the students when delivering new electronic devices. The students spend the first 11 of the 15 semester weeks working on a team project. They must define their teams, accept a rotating role as team leader, and work with their team to bring the semester project to a successful completion. The students spend the last 6 weeks of the semester (overlapping with the team project) on defining and proposing a project they will design and implement as their senior design project. The course includes three (50 min.) lecture periods each week over a fifteen week semester.

Approach

Key concepts relating to creativity in innovation were introduced over six lecture periods during weeks six and seven. The twenty-eight students enrolled in the course during the fall of 2009 were asked to write a one paragraph description of rough ideas for their senior design projects prior to the start of week six. Students were advised to include enough detail in the paragraph so that someone could read the description, with no further input from the student, and understand what the project entailed. This gave instructors the ability to use student-derived problems as the groundwork for classroom activities. Many creativity enhancement efforts involve external stimuli based on design problems, puzzles and exercises that are provided or created by someone else. Finding and formulating problems are key methods for helping students become more autonomous and less dependent on external rewards. Innovation is most often associated with the reframing of old problems in new way, but given that people approach and solve problems in the domains that interest them, giving students the opportunity to pose their own problems drawn from their day-to-day experience taps into the intrinsically motivating aspects of designing[8].

Lecture Materials and Class Activities

Week 1, Day 1: Introduction to Innovation

Students were introduced to broad categories of innovation, including product, process, market, social and organizational innovations; provided examples of incremental and domain-changing innovations; and reviewed the evolutionary nature of innovation in which strong characteristics of older systems are retained while technological, economic and social advancements drive mutations of other characteristics. The resource view of innovation, in which organizational resources, as outlined below, are leveraged as inputs into the innovation process, was introduced.
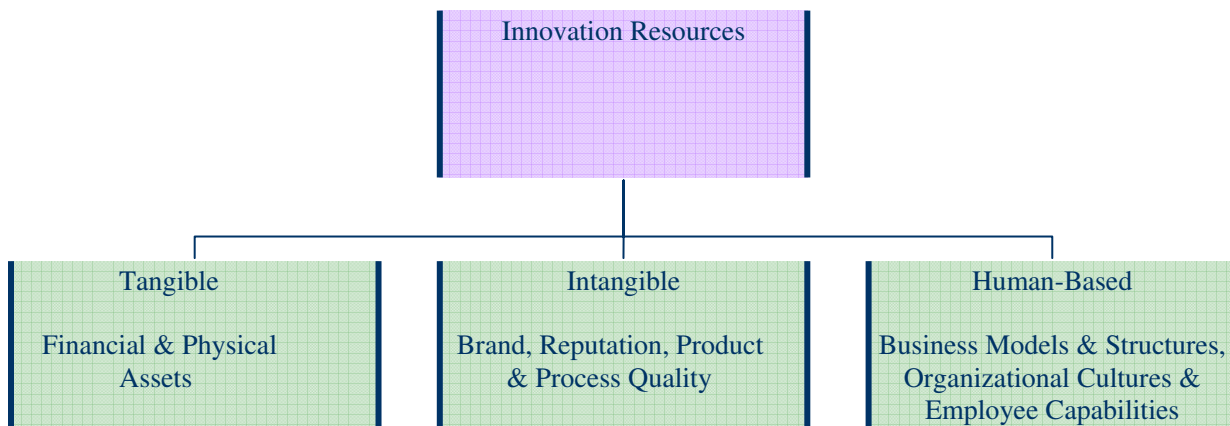

Figure 1 - Innovation Resources

This discussion was followed by a review of the creative processes in innovation, including idea generation and conceptualization, the up-front, problem finding processes of innovation where attempts are made to discover, formulate and conceptualize new and useful problems to be solved; and optimization and implementation, the problem-solving process of innovation, where feasibility, cost market, testing and implementation issues are addressed.
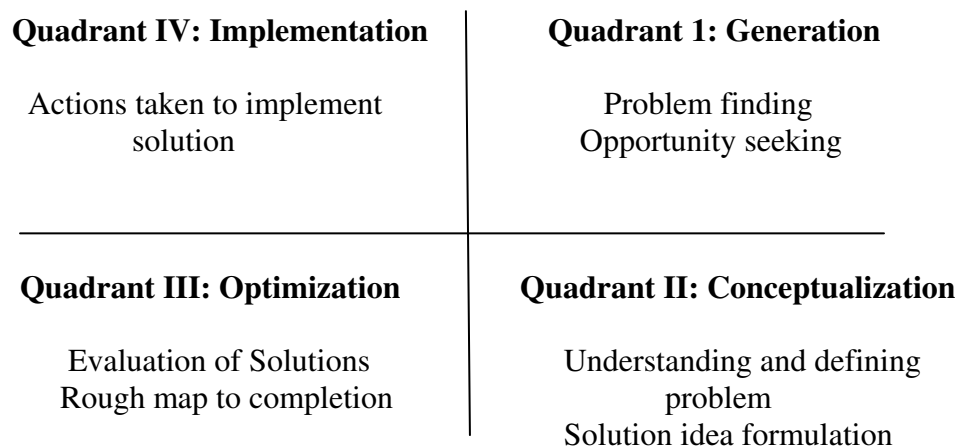
Quadrant IV: Implementation	**Quadrant 1: Generation**
Actions taken to implement solution	Problem finding Opportunity seeking
Quadrant III: Optimization	**Quadrant II: Conceptualization**
Evaluation of Solutions Rough map to completion	Understanding and defining problem Solution idea formulation

Figure 2 - The Innovation Processes

Activity: Students were asked to break into groups of 3-4. Students were asked to rate the project ideas of each member of the group on an evaluation form designed to measure key aspects of product creativity applicable during the idea generation and conceptualization stage. The form contained nine statements on a 5-point Likert Scale, with a score of 5 indicating strong agreement, and a score of 1 indicating strong disagreement. Three items (4, 7 & 9) were reversed scored. In item 10, students were asked to choose which of the three descriptive sentences best described the type of project proposed. Completed forms were submitted to the instructors for analysis.

	S A	A	N S	D	S D	Comments
1. The idea is highly creative.						
2. The idea could lead to a broadly applicable product.						
3. The idea could serve as a catalyst for further ideas/products.						
4. The problem does not respond to a clearly identified need.						
5. The proposed project fits the problem for which it was created.						
6. The problem description clearly communicates its purpose.						
7. The problem description appears incomplete.						
8. The idea shows evidence of careful thought and planning.						
9. The idea is not very easy to understand.						
Mark an "X" in ONE category below that best describes the idea proposed for the project:						Comments
10a.The idea is a truly new product.						
10b. The idea is a new "twist" to an existing product.						
10c. The idea is a routine product.						

Figure 3 - Project Creativity Metric

Week 1, Day 2: Creative Capabilities in Technological Design

The second lecture focused on the human resource element in the innovation process. Students were reminded of the broad reach of innovation, the stages in the innovation processes and were reminded that every individual has a preferred locus of creative work in that process. The major variables affecting the expression of individual creativity were presented, including insight processes, cognitive style, domain knowledge, motivational orientation, learning style, personality traits and behaviors unique to the individual; and environmental, cultural and social issues of broader import. Individual variables were then linked to elements in the grading matrix used during the final presentation of senior design projects in ECET 497.

Activity: Each student was given the project creativity evaluation forms completed by group members along with a chart that summarized their total and sub-factor scores. Handouts were provided to explain the three factors measured by the form, along with a summary chart organized by low, average and high total and factor scores for the class. Students were asked to return to their groups and work together to help each other improve performance on specific areas where aspects of their project ideas were evaluated poorly, and discuss comments made by group members on evaluation forms to improve project ideas.

Week 1, Day 3: Innovation and Creative Capabilities in Senior Design Projects

The final day of the first week included cautionary notes on technological design models. Students were reminded that linear design models try to impose order on what is essentially a confused interactive process. Students were advised to work through the innovative process in their own unique way while keeping focused on the end goal, and a series of questions were presented to encourage students to view the project as a future business.

Activity: A video presentation by IDEA entitled "Deep Dive" was shown to the class. This video follows a team of people with different areas of expertise employ the process of innovation to design a modern grocery cart. The video was followed by a discussion of the need to incorporate the ideas of potential customers and others outside of their domain as they work on solving the problems they've chosen for their projects.

Week 2, Day 4: Finding Solutions for Technological Design Problems

Lecture materials focused on techniques for finding creative solutions for problems identified in senior design projects. Criteria for evaluating which problem solving method, such as trial-and-error, brainstorming, brain-writing, nominal group techniques, analytical hierarchy processes, decision matrices and TRIZ, were presented. TRIZ was selected for further study since it's a heuristic-based, problem-solving method developed specifically for use in evolved engineered systems. A brief history of the TRIZ method was introduced, followed by a discussion of basic features of good technical solutions, an overview of the fundamental methods of TRIZ, the role of technical and physical contradictions in the method, and how separation principles are used to eliminate them. An overview of the use of the Contradiction Table and 40 Inventive Principles of TRIZ followed.

Activity: Students, assembled in groups, were provided with a 2-page worksheet, a 3-page TRIZ Guide designed to help them apply TRIZ principles to their senior design projects, and copies of the Contradiction Table and 40 Inventive Principles. Students were first presented with examples of physical contradictions and the separation principles used to resolve them, then were asked to explore if separation principles (space, time, between parts and wholes, and upon condition) could be used to resolve problems in their senior design projects.

Week 2, Day 5: Solution Finding Using TRIZ

The 9 Windows method of TRIZ was introduced following a brief overview of resources, contradictions, and the evolutionary nature of technological systems. The 9 Windows method helps define the complexity of problems by placing the parts of the system into their appropriate phase of evolutionary development. Problem solvers use 9 Windows by placing their problem in the center of a 3 X 3 matrix, identify the historical place (past, present or future) of each component in the system, add super-system language that describes the broader environment in the the system presently functions, then add subs-system descriptors for the components of the present system. The 9 Windows method helps problem solvers find creative solutions by helping

them identify components that have evolved unevenly; identify components that could be left out, developed or added; identify points where transitions to higher or lower level systems may be of benefit; or where interactions or components can be added to increase or decrease complexity.

Activity. Students were provided with worksheets and asked to re-assemble into groups. The worksheet (see Figure 4) included an 8-item questionnaire to help them define the who, what, when, where and why their particular problem occurs; identify the potential resources that are affected by the problem and those that can be brought to bear on the solution; and identify and label the underlying contradiction. A second activity involved modeling and intensifying the contradiction identified in the first activity by identifying the visible drawbacks, tradeoffs, inherent contractions and intensified contradictions in their design projects. The worksheet also included a 9-Windows diagram, where students were asked to break their projects down into systems, sub-systems and super-systems, and place components in their appropriate evolutionary place.

	Past	**Present**	**Future**
Sub-system			
System			
Super-system			

Figure 4: 9 Windows Diagram

Week 2, Day 6: Summary

Key points from prior lectures on innovation were reviewed and additional examples of TRIZ methods were presented. Students were encouraged to keep working on their projects using ideas, guidelines and methods provided during the 2-week project and websites were provided for students interested in learning more about the methods presented.

Preliminary Analysis

Project Creativity Metric

 An item analysis of the Project Creativity Metric indicated that two of the three variables, Resolution (R) and Elaboration (E), had a correlation value of 0.6 indicating these items may overlap to some degree, while the third factor, Novelty (N), had lower correlation values of 0.1

and 0.4 with the (R) and (E) scales. A Cronbach's Alpha of 0.6, less than the common benchmark of 0.7, suggests that the three items are measuring different constructs, however, omitting the Novelty scores from analysis raises this value to 0.7, while omitting the Resolution and Elaboration scores reduces this value to 0.5 and 0.1, respectively. Principle component and factor analysis suggested that the (N) scale was responsible for 60% of the variance in the data, while (R) and (E) explained 30% and 10% of the variance, respectively.

Future Directions

Students who participated in the 2-week program presented final senior design proposals to fellow students, faculty members and private sector designers in December, 2009. Work on the projects will continue as students progress through ECET 496/497, and given that most students will require 1-3 semesters to complete the sequence successfully, program effectiveness will be an on-going process.

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