AC 2011-1383: AN ASSESSMENT OF CREATIVE CAPABILITIES IN TECHNOLOGICAL DESIGN

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Exploring Creative Capabilities in Technological Design

Introduction

The ability of organizations to capitalize on rapid technological advancement effectively through the process of innovation is a primary means of generating value in the 21st century global economy. Innovation describes the broad process of developing, adopting and implementing new or significantly improved ideas, goods, services, processes or practices that are useful in some way. Innovation is a creative process and modern organizations require a certain confluence of resources in order to gain the most from their efforts. This innovative capability gives the firm its primary competitive advantage and the manner in which these resources are leveraged in support of the innovative process is vital to its economic success[1].

Successful innovation requires a unique set of intertwined resources 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. A variety of metrics have been developed to measure and track components of innovative capability, such as tools to track funding for research and development, and companies have adopted more flexible management systems and business structures; introduced innovative product and process quality systems; and focused on brand marketing in an effort to enhance their capabilities, but is the human resource[2]. It is the individual who carries the potential to be creative, and while this element is the most powerful and elusive force in the process of innovation, developing their unique creative capabilities through more focused, systematic and deliberate educational efforts is an investment in human capital.

Creative capabilities, a component of human-based resources, are individual skills, abilities and behaviors necessary for creative work in a given domain. Creative achievement at any level requires a certain threshold of cognitive, environmental and personality inputs, and the confluence of these resources influences the extent to which individuals will utilize and develop whatever genetic potential they might have. Each capability acts in the presence of others, such that a person's overall set of unique resources is what yields their creative capability or potential. Research on the history of creativity and leadership, however, suggests that while creative people share some common capabilities across domains, individuals most often express creativity in only one domain, such that all creative acts in that domain share an underlying unity[3]. Domains can be represented in a multidimensional space, but some domains, such as technology and science, are closer to each other in Euclidean distance than other domains, such as art and accounting[4]. One of the principal 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, therefore, are first judged on issues relating to effectiveness, i.e., does the product solve the problem it was intended to solve within design constraints, such that effectiveness takes priority over novelty and originality, though both must exist for a product to be considered creative. Even then, the value of the creative product is ultimately judged by its success in the market, whereas in artistic creativity, novelty alone may define its merit to society. This is a particularly notable distinction in the domain of technology, since new products often become inextricably linked to other domains via the evolutionary nature of the innovation process, and the speed with which the creative products become diffused throughout society.

There is a growing consensus that general- and domain-specific creative thinking skills and traits of value in the innovation process need to be deconstructed and redefined within domains. Enhancing student creative capability is an important goal of education in an innovation economy, yet while a wide variety of creativity training programs exist; most are based on the model that creative thought is rooted in a general skill set. Featuring general training techniques to foster divergent, critical and evaluative thinking, these programs tend to assume, whether implicitly or explicitly, that well-designed general creativity training programs can enhance the capability across domains, yet there is significant evidence to suggest that this is not the case[5].

Creativity in Technology and Design

The impact of the diffusion of technology into most aspects of human existence has fundamentally changed the way in which the role of technology in education, and education about technology, is viewed. Modern technology education models that focus on design as the core problem-solving process are based on the belief that teaching students how to use the design process increases knowledge about technology, develops capabilities in using technology, and expands cognitive skills and critical thinking capabilities[6]. There is little doubt that design can be an iterative, systematic and creative problem-solving process that enhances critical thinking ability, knowledge of technical content and understanding of economic and social effects of technology, but not all design activities are equal. Some have argued that design as a pedagogical method lacks linguistic simplicity if efforts to enhance capabilities necessary for solving innovative problems, as opposed to the routine, are absent from the curriculum[7.]

Different creative capabilities, at the very least different levels of each, are required to solve problems across the technological spectrum, yet little is known about the level of capability among students in the domain, how those capabilities influence creative work in the domain, or how the judgment of creativity in the domain reflects capabilities and/or influences their expression. The content of creative capability enhancement efforts in technological design projects is difficult to determine when there is little understanding of what those capabilities actually are or how well they assessment measures adequately capture them. There is increasing evidence that capabilities that are most useful in solving straightforward, algorithmic problems may not play the same role in solving more innovative problems. Innovation and invention are among the most open-ended and creative activities in technology, yet there are few examples of what behaviors and cognitive processes are unique to this type of problem. Problems such as these do not have precise starting or ending points and are solved by a combination of strategies that come from memory, readily available knowledge, and strategies that may have to be created by the solver. Generic design instruction, while demonstrably useful in technology education, may not provide the tools and skills required for solving problems at the innovative end of the technology spectrum[8].

Componential theories of creativity and innovation follow a hybrid approach that allows for the development of programs centered on developing both domain-specific and domain-general characteristics of creative capabilities. The broad personal factors of importance in componential theories of creativity are defined along three dimensions, including domain specific skills and knowledge, personality traits linked to highly creative behavior, and environmental conditions known to support the creative enterprise. Individual creative capabilities are a complex blend of cognitive characteristics, such as thinking style, knowledge, and insight process skills; and personal attributes, such as motivation, confidence, risk-taking comfort, creative personality traits, etc., and organizational structures, practices, resources and cultural considerations tend to support or detract from these natural capabilities. Novel ideas, processes, methods and techniques are at the root of the innovative process in technology, thus the importance of educational programs that cultivate not just knowledge and skills, but dispositions and attitudes of open-mindedness, curiosity, and risk-taking[9].

Many creativity enhancement efforts involve external stimuli based on design problems, puzzles and exercises that are presented by someone else, but finding and formulating problems are key methods for helping students become more autonomous and less dependent on external rewards[10]. There is a substantial body of research in business, psychology and education describing how experts differ from novices in terms of both the quantity and quality of their problem-solving skills. There is also broad agreement in the technology education community that design is not only a craft skill but also a way of thinking, but there is dearth of research regarding what skills, abilities and behaviors are essential for creative work in the domain and how best to capture the essence of creative behavior.

Project Description

The focus of this project was largely exploratory in that it was designed to shed light on the relationship between creative capabilities, including personality traits and behaviors, insight abilities, motivation, cognitive style, domain knowledge, and learning style; and existing measures of creative production in an electrical and computer engineering technology (ECET) senior design project. Componential theories of creativity suggest that there are aspects of the creative process that are domain-specific such that efforts targeted toward enhancing the generation of creative products must be grounded in domains of practice. There is a dearth of research regarding not only the creative capabilities deemed important in the domain of technology but also how well assessment systems capture the more creative aspects of the process. The interest in studying the relationship between creative capabilities and creative production is driven by the belief that all individuals have the potential to be creative; that creativity is an essential aspect of the design process; and that certain aspects of creative potential are malleable and can be enhanced through practice. Studying creative capabilities and products in an open-ended design project can inform not only what capabilities students bring to the classroom, but also how project assessment measures capture these essential capabilities.

The study population was drawn from students enrolled in Project Development and Management, a course in electrical and computer engineering and technology (ECET) required of students in the major. The 4-credit junior-level course provides a structured introduction to electronic projects, with an emphasis on planning and design alternatives to meet cost, performance, and user-interface goals. One of the course requirements is the completion of the conceptualization and initial development phases of an electronic device that accomplishes a student-defined task or solves a student-defined problem. Student projects are taken to completion in two subsequent self-directed laboratory courses, Project Design and Development, Phase I and II. The students who volunteered to participate in the study (n=40) ranged in age from 21 to 35, and most were white, non-Hispanic males from within the state, with nearly half of them starting as freshman in the ECET program. The cohort included 1 female, 3 African-Americans, 3 Hispanics and 1 international student.

Procedures for Measuring Creative Capabilities

Forty students agreed to complete 5 instruments designed to measure unique aspects of creative capability during the conceptual phase of their senior design projects in ECET396. The creative capabilities and metrics selected for inclusion in this project included:

(a) Ideational abilities: The Adult Torrance Test of Abilities (ATTA) [11];
(b) Cognitive style: The Cognitive Style Index (CSI) [12];
(c) Learning style: The Approaches and Study Skills Inventory for Students (ASSIST) [13];
(d) Motivation: The Work Preference Inventory (WPI) [14]; and
(e) Personality traits and behaviors: Katina-Torrance Creative Perception Inventory (KTCPI) [15].
(f) Student knowledge of the rules and procedures of the domain was measured by calculating the GPA from a measure of eight sophomore and junior-level ECET courses required of a major in the field (TGPA). The courses included 4 analog courses, 1 digital/micro course, 1 power course and 2 professional development courses. An outline of factors measured by each method is outlined in Table 1.

Table 1
Measures of Creative Capabilities

Capability	Instrument	Factors
Ideational Ability	ATTA	Fluency, originality, flexibility, & elaboration
Cognitive Style	CSI	Intuitive & analytical cognitive style
Learning Style	ASSIST	Deep, surface & strategic approaches
Motivation	WPI	Extrinsic & intrinsic motivational orientation
Personality	KTCPI/SAM	Environmental sensitivity, initiative, self-strength, intellectuality, individuality & artistry
	KTCPI/WKOPAY	Acceptance of authority, self-confidence, inquisitiveness, awareness of others & disciplined imagination
Domain Knowledge	TGPA	8 courses required of major in ECET

Procedures for Measuring Creative Production

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. Viewing creativity as a cause helps describe the individual characteristics of students entering a given domain so that enhancement efforts are more effectively targeted. Looking at creativity as an effect helps illuminate the gap between individual creative capabilities and way their creative products are judged, which serves as a reminder to the gatekeepers of the domain that we are what we measure.

The first measure of creative production included final scores on the conceptual phase of proposed senior design projects in ECET396, while the second measure of creative production included the summed innovation and design scores from an existing faculty-developed rubric used during the final presentation of senior design projects. The rubric were developed specifically for the assessment of senior design projects and have been used for a number of years, but there are no explicit links between the assessments and specific courses, nor is any claim made that the metric specifically measures constructs relating to creativity in technological innovation. An outline of the relationship between capability and performance measures is outlined in Figure 1.

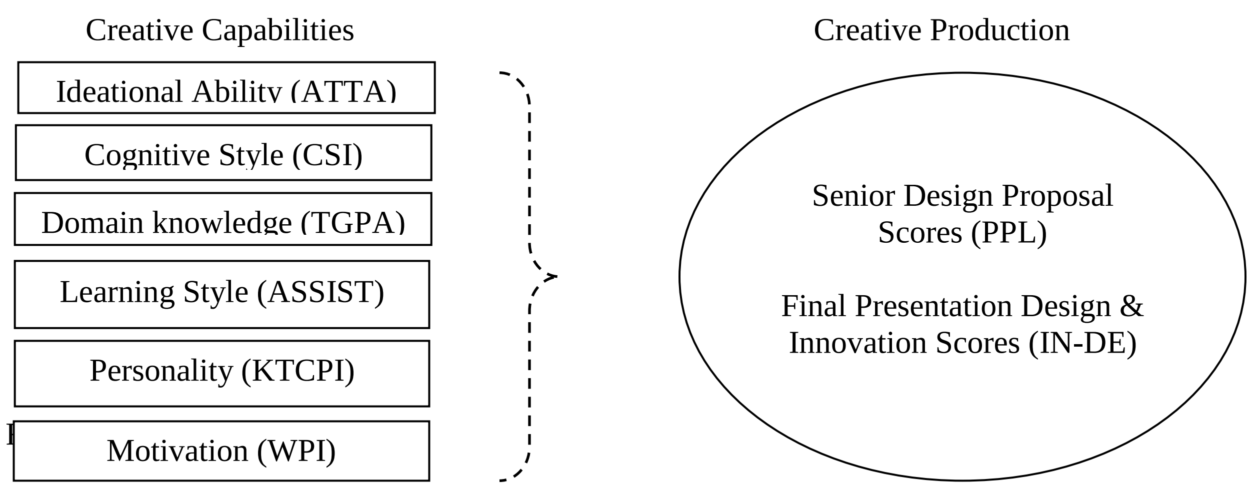

Figure 1: Measures of Creative Capabilities and Creative Production

Grades on the senior design draft proposal represent an assessment of the early stages of creativity in technological design. The identification of a unique technological problem in an open-ended design project is a creative act, such that the identification of student strengths and weaknesses at the front-end of the process helps illuminate the product creativity question by focusing on the early conceptual elements of creativity in design. Creative performance in capstone design courses, however, cannot be fully assessed in the absence of a product or tangible device, since the devices themselves serve as proxies for technological skills mastery, of which creativity is a factor [16]. The second product creativity metric, therefore, included the summed innovation and design scores from the ECET497 Final Presentation Grade Sheet, a seven-factor, faculty-developed metric used to evaluate final student projects and presentations. Each student project ($n=28$) was rated by a panel of three or four judges, including at least one private sector domain expert and several members of the ECET faculty.

The analysis of the preliminary data included a comparison of sample scores on each measure of creative capability with population norms reported by instrument developers, and in the case of TGPA scores, on norms reported by faculty over a 3-year period. A one-sample z-test, with a criterion value of $\alpha = 0.05$, was used for the analysis. This was followed by a correlational analysis between each capability metric and the total project proposal score and the combined innovation/design score from final project presentation grading rubric.

Students in this cohort scored significantly higher than population means on measures of total insight ability, as measured by the ATTA ($z = 2.83$, $p=0.005$). This finding suggests that students in the cohort have higher than average capabilities regarding the ability to produce a number of uncommon or unique ideas and process information in unique ways. Performance on the CSI, a measure of cognitive style, indicate that students were slightly, though significantly, higher than population scores ($z=2.15$, $p=0.032$), indicating a more analytical style orientation. Analytical thinkers tend to rely on mental reasoning, logic and systematic methods of investigation, prefer verbal content to spatial images, but are more conformist and somewhat uncomfortable with rapid change.

Domain-specific grades (TGPA) also suggested a cohort with significantly higher than student averages ($z=5.82$, $p=<0.005$), while scores on the surface scale of the learning style inventory (ASSIST) were significantly higher than the population average ($z=3.25$, $p=0.001$). A higher surface score indicates an unreflective approach to the learning process, difficulty in integrating knowledge and making sense of new material, and a preference for routine procedures and rote memorization. Student scores on measures of personality and behavior traits associated with creativity (KTCPI) were significantly higher than population norms ($z = 3.59$, $p<0.05$). Higher scores on the KTCPI reflect a more creative personality, a preference for creative thinking strategies and an historical pattern of creative production.

Students were significantly more extrinsically motivated than population norms on the extrinsic scale on the measure of motivational orientation, the WPI ($z = 2.72$, $p=0.007$), and significantly lower than population scores on the intrinsic scale ($z = -2.39$, $p=0.017$). Sub-score analysis indicated a strong average tendency to be motivated by outward demands, a need for recognition, a sensitivity to the opinion of others and a desire to work with clear goals and procedures, while also reflecting a lower than average motivational orientation toward self expression, curiosity, goal setting and enjoyment.

Students who participated in this study scored significantly higher than normative measures on measures of insight ability (ATTA), knowledge (TGPA), and creative personality and behavioral traits (KTCPI), suggesting strong creative process skills, solid knowledge of the content, rules and procedures in the domain, and a personality that is orientation toward creative thought and action. In contrast, lower than average scores on the measure of cognitive style (CSI), a high score on the surface approach to learning (ASSIST), and an orientation toward extrinsic motivational factors (WPI) suggest the presence of negative forces on creative behavior.

An analysis of the relationships between the capabilities measured and measures of creative production was then conducted by calculating correlation coefficients between each of the six measures of creative capability and both measures of creative production. The results of that analysis are outlined below.

Table 1

Correlation Coefficients for Creative Capability and Production Measures

	ATTA	CSI	TGPA	KTCPI	LS-ST	LS-DE	LS-SU	WPI	PPL
PPL	-0.014 0.945	0.035 0.861	**0.513** **0.005**	-0.033 0.867	**0.402** **0.034**	0.183 0.350	-0.305 0.115	0.274 0.158	
IN-DE	-0.097 0.622	**0.411** **0.030**	**0.451** **0.016**	-0.112 0.569	0.226 0.248	0.059 0.767	0.056 0.777	0.140 0.478	0.005 0.979

Note. Cell Contents = Pearson correlation/p-value. Correlations significant at $\alpha = 0.05$ are in boldface; ATTA = Abbreviated Torrance Test for Adults; CSI = Cognitive Style Inventory; TGPA = Grade point average in ECET-specific courses; ASSIST = Approaches and Study Skills Inventory for Students; KTCPI = Katina Torrance Creative Perception Inventory; WPI = Work Preference Inventory; PPL = Senior Design Proposal score; IN-DE: Innovation and Design Scores from ECET497 Final Presentation metric.

Looking first at the relationships between proposal scores and capabilities, a slight negative correlation was noted between the proposal scores and scores on the ATTA, KTCPI and the Surface Scale of the ASSIST, while a slight positive correlation was found between the proposal scores and the CSI, the Deep Scale on the ASSIST and the WPI. The TGPA and Strategic Learning Style, however, shared a moderate, statistically significant linear relationship with the Proposal Scores. This phase of the senior design project requires both the ability to identify a unique technological problem and the ability to identify unique conceptual elements of a solution. Students who are more familiar with the technological content of the domain, represented by the TGPA measure, should have the basic skills necessary to identify problems within the domain, but a preference for strategic approaches to learning may not be as useful in the open-ended demands required of the early phases of the senior design project. A deep approach to learning, where the focus is on an in-depth understanding of underlying concepts that transforms the way the world is viewed, may be the more helpful orientation in the early phases of a design project, where surface and strategic learners may struggle.

A stronger, positive relationship was found between the final innovation and design score and cognitive style, suggesting that the lean toward analytical thinking may be beneficial in the later, more iterative phases of the design project. The continuation of a positive correlation between the TGPA score and the final innovation and design score also suggested that greater domain knowledge remained beneficial throughout the project. The analysis of the preliminary data outlined in this paper was followed by a more in-depth analysis of the relationship between principal sub-factors measured by each instrument and their relationship to other factors measured on the Final Presentation metric.

Future Directions

The goal of this project was to provide guidance for teachers of technological subjects as they prepare students for life and work in an innovation economy where creative capabilities are a highly valued human asset. The value placed on creative behavior in a given domain is often reflected in the way creative production is measured, which is heavily influenced by gatekeepers, including educators, professionals, journal editors, and leaders who maintain and promote organizational structures, practices, and resources that define, promote and constrain creative work in that domain. Instructional practices that reinforce a conformist, algorithmic approach to learning can stifle individual creative effort, so while it is essential that technology educators provide a certain level of content knowledge and skills, it is also important to provide students with the opportunity to learn adaptive and innovative approaches to problem solving.

Coupled with findings from similar studies in related domains, the information gained from this project is being used to identify areas in which malleable aspects of student creative capability can be incorporated into the project management course (ECET396) for maximum impact. A series of lectures and skill sessions designed to help students tap into their unique creative capabilities is under development, as are assessment tools for measuring specific aspects of creative performance believed to be of relevance in the more innovative aspects of technological design.

An additional goal of the 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. Short-term, the focus of these efforts is targeted toward a narrow demographic, but the long-term goal is the development of creativity enhancement efforts that reflect what is specifically valued in a broader spectrum of technology-related fields.

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