# Chapter 7
# Creative Engineering Design: The Meaning of Creativity and Innovation in Engineering

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> *The word "engineer" comes from the Latin "Ingeniatorum" meaning "ingenious" with "gen" Referring to Creation, the act of Creation or "Genesis" The essence of the words "creativity" "create" and "engineer" Stem from the act of creation.*
>
> *Creativity is no longer an optional accessory. Instead, creativity is a necessity for innovation and prosperity, especially now during our current global and economic times. Creativity and innovation are vital in the United States of America, the Americas, Europe, Asia and the entire world, especially now in our current era.*

**Abstract** The importance of creativity as a vehicle for innovation in engineering design is discussed in this chapter. A creative act needs acceptance of an idea, product, or process by the field, such as engineering and the domain such as science or Science, Technology, Engineering and Mathematics (STEM). Today's engineers must be creative and innovative. The problems engineers facing today demand original thinking. To remain competitive globally, engineering firms rely on creative individuals and creative teams to develop new products for innovation. The Creative Engineering Design Assessment (CEDA) offers a new method for assessing creative engineering design. **Unlike previous measures, the revised CEDA also measures Originality and Usefulness, which, to date, is a unique component when compared to other general creativity and engineering creativity measures.** Creative design and its measurement may act as a catalyst to increase enrollment in STEM. Through prioritizing creativity and innovation, as we did with prioritizing scientific creativity in the 1950s, we can enhance global prosperity, not only for the United States of America (USA) but also for other countries around the world.

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## 7.1 Introduction

Creativity research in engineering began to blossom in the 1950s (Ferguson 1992). The recommendations of Vannevar Bush, an electrical engineer from MIT, led to establishment of the National Science Foundation in 1950. At the same time in psychology, American Psychological Association President, J.P. Guilford stated a need for creativity research (Guilford 1950). "The research design, although not essentially new, should be of interest" (Guilford 1950, p. 444). A creative pattern is in creative behavior, which includes activities such as inventing, designing, contriving, composing, and planning. People exhibit these types of behavior are recognized as creative. Guilford (1950) noted a key trait of creative people in that they have novel or new ideas.

In the early 1960s, the National Science Foundation (NSF) sponsored conferences on "scientific creativity." Yet, "as interest in engineering design faded in most engineering schools, creativity was put on a back burner" (Ferguson 1992, p. 57). More recently, creativity has received greater attention as a necessity for engineering design (Charyton and Merrill 2009). Currently, creativity is increasingly important as a vital resource.

Creativity is the most important of all human activities. Many homes and offices are filled with furniture, appliances, and other conveniences that are products of invention (Simonton 2000). Czikszentmihalyi (1999) suggested that the person, domain, and field are relevant to understanding creativity and innovation. This theory postulates that there needs to be acceptance of an idea, product, or process by the field such as engineering and the domain such as science or Science, Technology, Engineering and Mathematics (STEM).

Creativity and innovation are key in most levels of engineering education, yet these topics are rarely expressed, investigated, or studied explicitly in coursework (Forbes 2008). Without training in the fundamentals of creativity, only 3 % of the population associate creativity with engineering (Stouffer et al. 2004). However, there is consistent interest in engineering education to address creativity and innovation within the curriculum. For example, Ishii and Miwa (2004) found idea generation, idea embodiment, and collaboration of creative activities as important activities for learning. Projects with a keen personal investment may increase the commercialization of invention (Ruiz 2004).

## 7.2 Why Creativity is Still Needed in Engineering Design

The problems engineers facing today demand original thinking. To remain competitive globally, engineering firms rely on creative individuals and creative teams to develop new products for innovation. Design News (2007) reported that 65 percent of engineers in the workforce (from mechanical, application, and manufacturing engineering companies) agreed that today's engineers need to be more creative and innovative to be globally competitive (Christiaans and Venselaar 2005).

Specific to engineering, engineers may increase creative production through understanding their domain-specific constraints. Stokes (2005) described how different types of constraints (tasks, goals, subjects, functions, materials, and styles) may be unique to specific domains. Research by Finke, Ward, and Smith (1996) found that the relative number of creative inventions increased significantly as the task became more highly constrained. Constraints on design may need further assessment as technology evolves (Mahboub et al. 2004; Redelinghuys 2001; Waks and Merdler 2003).

Engineers can learn to use tools such as technology for design (Jones 1995), yet human beings are vital (McDougnel and Braungart 2002) for innovation in design. Products are sometimes invented by users to improve our everyday lives in relation to social functions (Von Hippel 2005). For example, communication tools that utilize technology often benefit consumers. Engineers can foresee potential consumer needs for products. These products can increase productivity and contribute to innovation and the future of the engineering field (Jones 1995).

## 7.3 The Importance of Creativity and Innovation for Engineers Beginning in Education

Today's engineers must be creative and innovative; there is a pressing need that creativity and innovation in engineering begin in educational settings (Fleisig et al. 2009). The encouragement of creativity is vital in schools and curricula (Romeike 2006). Education has the power to cultivate or stifle creativity (Burleson 2005). Creativity is enhanced by confidence, self-development, and a positive mind-set (Kang et al. 2011).

Creativity may be expressed as visualizing and manipulating images, greater openness to experience, and evaluating ideas (Hawlader and Poo 1989). Ito et al. (2003) suggest that imagination is attained by touching the concrete. These authors also suggest that creative education enables students to make innovative products while promoting integrated cooperation. Sulzbach (2007) notes a recent graduate emphasized teamwork, leadership, creative thinking, and problem solving "-no grades attached. That is the engineering student I want to hire."

Engineering education is a paramount in providing the nation with innovative, creative, and critical thinking human capital that contributes to sustainability of the economy (Yasin et al. 2009). Creativity should be a vital part of engineering education as well as an important student outcome (Chiu and Salustri 2010) that contributes toward the workforce.

## 7.4 Creativity and Meta-Cognitive Abilities in Engineering Education

According to Nickerson (1999), creative problem finding may offer another avenue to increase creative production in engineering and needs further research. Furthermore, problem finding has not been a major focus of education. However, problem finding is common for an engineering designer needing to solve unforeseen problems (Ferguson 1992).

Psychology is valuable for addressing creativity in education by promoting learning through meta-cognition and self-reflective activities (Ishii and Miwa 2005). Empirical studies in educational and cognitive psychology literature address methods for learning. These methods have been implemented successively in engineering classes. Real-world applications, cooperative learning, active learning, and deductive and inductive learning are important for developing creativity (Felder et al. 2000). Reflection-in-action is learning by doing Schon (1983) which is important in engineering and other disciplines. Students need the opportunity to practice skills before they are assessed. Furthermore, experiential learning provides their students options to select assignments and promotes deeper learning.

The method of teaching creativity to engineering students has also been a key concern (Salter and Gann 2003). Engineering is essentially a creative topic that can be taught (Velegol 2014). Engineering creativity specifically encompasses problem finding and problem solving. However, problem finding has not been a major focus of engineering education. According to Nickerson (1999), creative problem finding offers another avenue for increasing creative production in engineering. Problem finding is common for an engineering designer who needs to think about and solve unforeseen problems (Ferguson 1992). An engineer's imagination and creativity have the power to develop technological solutions to problems (Deal 2001). Solutions can be achieved through both problem finding and problem solving.

## 7.5 Central Themes Specific to Engineering Creativity

Central themes specific to engineering creativity include Originality (novelty) (Shah et al. 2003; Thompson and Lordan 1999; Weisberg 1999) and Usefulness (applicability) (Larson et al. 1999; Shah et al. 2003; Thompson and Lordan 1999). Engineers not only need to address aesthetics—like artists, but they also need to solve problems, prevent potential problems, and address utility within the constraints and parameters that have been designated. Furthermore, a creative aspect of engineering has been described as "functional creativity" (Cropley and Cropley 2005).

Functional creativity means that products designed by engineers typically serve a functional and useful purpose, unlike fine art. Creative products emphasize novelty, resolution, elaboration, and synthesis (Cropley and Cropley 2005). Building on this, problem finding may offer another avenue for increasing creative production (Nickerson 1999). Problem finding is a skill often found in art, yet is also necessary in science and engineering. Both problem finding and problem solving are relevant to an engineer's creativity; however, both attributes have not been measured in much depth in engineering creativity specifically. These attributes need to be assessed and further developed by educational activities (Cropley and Cropley 2005).

## 7.6 Measurement Needs for Engineering Creativity

The need for creativity in engineering has led to the development of numerous creativity support tools to enhance the creative design process (Baillie and Walker 1998). These tools not only address technology for the creative process, but also include measurement for assessment. However, to date, previous measures of engineering creativity have been limited. According to the literature available, only a few measures were developed to assess creative abilities in engineering design. These include the Owens Creativity Test (1960) and the Purdue Creativity Test (1960).

### *7.6.1 Engineering Creativity Measures*

#### 7.6.1.1 Owens Creativity Test (1960)

The Owens Creativity Test (Owens 1960) was developed to assess mechanical engineering design. Test takers list possible solutions to mechanical problems (divergent thinking). Reliability ranged from 0.38 to 0.91, while validity ranged from 0.60 to 0.72. Validity was determined via the testing of the engineers in mechanically related occupations. This assessment tool is out of print and is no longer used.

#### 7.6.1.2 Purdue Creativity Test (PCT) (1959, 1960)

The Purdue Creativity Test (PCT) was developed by Lawshe and Harris (1960) as an engineering personnel test, as a method for identifying creative engineers and their occupational potential. Participants are instructed to list as many possible uses for one or two shapes that are provided. The PCT has adequate reliability (0.86 to 0.95) and modest validity (29–73 % for low scorers and high scorers, respectively). Validity was determined by assessing professional engineers (process and product engineers) working in industry. Participants are instructed to generate original and novel possible uses for single objects or pairs of objects. Scoring is based on Fluency (number of uses) and Flexibility (differing categories of uses).

Although a reliable and valid measure, limitations include little use in field of engineering. This assessment measures engineering creativity only by assessing Fluency (number of responses) and Flexibility (categories of responses) and does not directly assess Originality. Both the Owens Creativity Test and the Purdue Creativity Test are limited in that they only measure divergent thinking (generating different solutions to a problem) by asking participants to list potential uses.

## *7.6.2 Creative Engineering Design Measure*

### 7.6.2.1 Creative Engineering Design Assessment (CEDA) (2008, 2011)

The Creative Engineering Design Assessment (CEDA) offers a new method for assessing creative engineering design. Participants are asked to sketch designs that incorporate one or several three-dimensional objects, list potential users (people), as well as perform problem finding (generate alternative uses for their design) and problem solving in response to specific functional goals. Sketching is instrumental in design problem solving (Goldschmidt and Smolkov 2006) and results in creative solutions. Some speculate that engineers think in pictures (Grandin 2006; B. Gustafson, personal communication, May 25, 2010). The sketching aspect of the CEDA is engineering specific and useful for spatial manipulations that are specifically necessary for engineering design.

Creativity in psychology has traditionally emphasized divergent thinking skills (open-ended multiple solutions to a problem) (Torrance 1974; Guilford 1984). In the CEDA model, convergent science and divergent practices are integrated as necessary functions for creative engineering design. Schon (1983) reported that engineers have become aware of the importance of actual practice that encompasses uncertainty, complexity, and uniqueness in convergent science and divergent practices. Engineering often requires the need to solve problems in these types of ambiguous situations. However, deriving alternative solutions through problem finding is essential. Both *problem solving* (generating the solution) and *problem finding* (identifying potential other problems) are important for creativity in engineering.

In order to be creative in engineering, solving problems is vital; however, determining when there is a problem to solve may be even more important (Ghosh 1993). Creativity support tools have focused on generating possible solutions, but not on identifying new problems (Baillie and Walker 1998). Yet, despite the importance of *problem finding* (identifying current problems or recognizing potential problems that may occur), the literature in engineering has traditionally been meager. This is true for both assessing engineering creativity and problem finding. To date, the Creative Engineering Design Assessment (CEDA) is one of the only tools to date that assesses both *problem solving* and *problem finding* (Charyton et al. 2008).

The CEDA builds on and improves upon features of the Purdue Creativity Test (Lawshe and Harris 1960) as well as Guilford's (1984) model of divergent thinking in that the questions are open-ended. The CEDA also assesses Fluency (number of ideas), Flexibility (categories of ideas, types of ideas, grouping of ideas), and Originality (new ideas, novelty). However, the CEDA differs from the Purdue Creativity Test in that it was not designed solely as a divergent thinking test. Furthermore, the CEDA was developed to specifically measure creativity unique to engineering design. Design is crucial for creativity and innovation for *users* and customers (Cockton 2008). Furthermore, participants sketch their own designs. Jordan and Pereira (2009) found that sketching was valuable for teaching engineering design. The CEDA has been demonstrated to be specifically related to engineering creativity and spatial skills while measuring aspects that are unique to engineering design.

Engineering creativity involves both *convergent thinking* (generating one correct answer) and *divergent thinking* (generating multiple responses or answers) (Charyton et al. 2008; Charyton and Merrill 2009). In the CEDA, students are asked to generate up to two novel designs to fulfill a generalized goal. The rationale for this limit is to work within the time *constraints* of the test and to elicit higher-quality responses. Also, because there are five steps to each design, the process requires more elements than just listing uses. In the CEDA, *divergent thinking* is assessed by generating multiple solutions. *Convergent thinking* is assessed by solving the problem posed. *Constraint satisfaction* is assessed by complying with the parameters of the directions and also adding additional *materials* and manipulating the objects as desired. *Problem finding* (identifying other potential problems) is assessed by identifying *other uses* for the design. *Problem solving* (finding a solution to a specific problem) is assessed by deriving a novel design to *solve the problem* posed.

**Unlike previous measures, the revised CEDA also measures Originality and Usefulness, which, to date, is a unique component when compared to other general creativity and engineering creativity measures.**

## 7.7 Current Measurement Contributions: The CEDA (Creative Engineering Design Assessment)

### *7.7.1 Theoretical Framework of the CEDA*

Figure 7.1 describes how each item on the CEDA addresses these theoretical constructs. *Divergent thinking* is assessed by generating multiple solutions to the problem. *Convergent thinking* is assessed by solving the problem posed by creating at least three designs for three problems. *Constraint satisfaction* is assessed by complying with the parameters of the directions and also adding additional materials and manipulating the objects as desired. *Problem finding* is assessed by identifying other uses for the design. *Problem solving* is assessed by deriving a novel design to solve the problem posed. This means solving the problem appropriately yet in a novel manner.

A readability and comprehension analysis was conducted on the CEDA to determine the appropriateness for college students. The analysis measure known

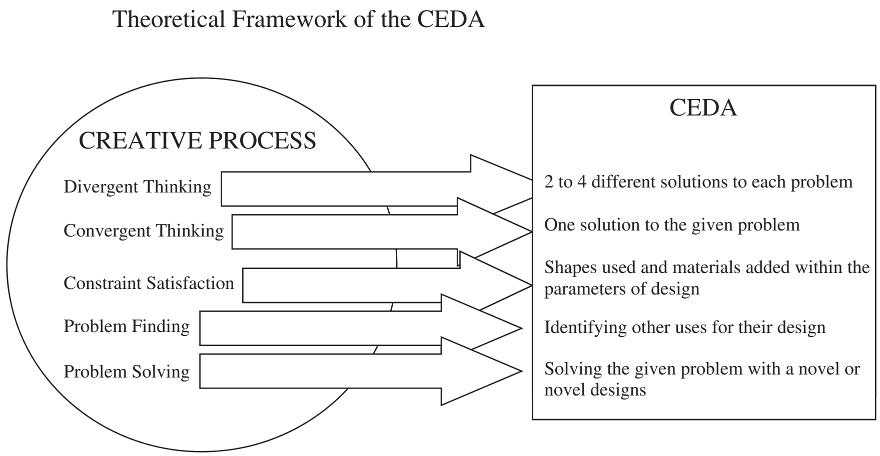


**Fig. 7.1** Creative Engineering Design Assessment meta-cognitive processes measured

as the Simple Measure of Gobbledygook (SMOG) (McLaughlin 1969), an online program, http://www.harrymclaughlin.com/SMOG.htm, was used to assess the reading and comprehension level of the CEDA. The SMOG is designed for evaluating the reading level of materials that can be read independently by a person without assistance from a teacher or instructor (Richardson and Morgan 1990). Readability is recommended at the 6–8th grade level for educational materials for the general public. The SMOG Grade for the CEDA was 8.81, being the 8th grade level, equivalent to a junior high school, which relates to a newspaper reading comprehension level. Therefore, the CEDA would also be appropriate and useful for precollege students at the junior high and high school levels.

### *7.7.2 Components of Scoring*

Figure 7.2 depicts the correlations among the components of the CEDA. The strong correlation (r = 0.86) between Fluency (number of ideas) and Flexibility (types of categories of ideas) reflects that both measure divergent thinking in terms of number of designs, although Flexibility uses more categorical analysis. Given this greater abstraction for Flexibility, it is perhaps not surprising that its correlations with Originality (novelty of ideas) ($r = 0.58$) and Usefulness (practicality for potential or current uses as well as number of potential uses) ($r = 0.46$) are numerically higher than those for Fluency ($r = 0.46$ and $r = 0.39$, respectively). The relatively high correlation between Originality (new ideas) and Usefulness (practicality) ($r = 0.65$) is perhaps surprising, given that these are distinct constructs that are both central to engineering creativity. However, their relationship may be higher in an engineering population, which values both Originality and Usefulness more than other fields or domains.

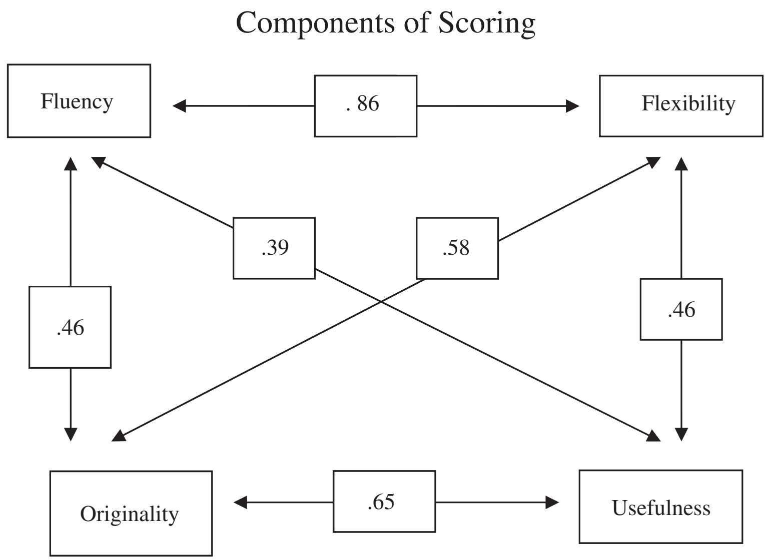


**Fig. 7.2** Correlations among the components assessed within the creative engineering design assessment (CEDA). Fluency is the amount of responses. Flexibility is the amount of types or categories of the responses per problem. Originality is novelty or new ideas that are assessed based on a rubric consisting of descriptors and numbers on a scale from 0 to 10. Usefulness is the practicality of the design for current and/or potential future uses on a Likert scale from 0 to 4

The inter-rater reliabilities between the four engineering judges and the one psychology judge were calculated for each of the components, except Fluency, which simply consisted of a count of items. The reliabilities for Flexibility ($r = 0.83$, $p < 0.01$), Originality ($r = 0.59$, $p < 0.01$), and Usefulness ($r = 0.46$, $p < 0.01$) were lower than the inter-rater reliability of the overall CEDA scores without Usefulness ($r = 0.92$, $p < 0.01$) and with Usefulness included ($r = 0.81$, $p < 0.01$). The magnitude of the reliabilities indicates the difficulty of judging Originality and Usefulness. The higher reliability of the overall CEDA scores is based on a combination of these component measures. The CEDA is comparable to the PCT on Fluency and Flexibility.

## *7.7.3 Properties of the CEDA*

### 7.7.3.1 Reliability (Continued)

Previous correlations among the CEDA scores of two judges were conducted to identify their relationships with each other and establish reliability. Judges were in agreement ($r = 0.98$) with their overall scoring. Inter-rater reliability was high for Flexibility ($r = 0.90$ and $r = 0.98$) and Originality ($r = 0.80$ and

$r = 0.85$), indicating consistency in both test and retest measures, respectively (Charyton and Merrill 2009). The CEDA was consistent for the test and retest reliability ($r = 0.56$) like the other general creativity measures such as the Creative Personality Scale (CPS) ($r = 0.57$), Creative Temperament Scale (CT) ($r = 0.51$), and Cognitive Risk Tolerance Scale (CRT) ($r = 0.43$), $p < 0.01$, for all comparisons (Charyton and Merrill 2009).

Reliability was important to reestablish since we modified the CEDA to assess Usefulness in addition to Originality. The four engineering judges were in agreement with the psychology judge at the following levels ($r = 0.95$), ($r = 0.88$), ($r = 0.91$), and ($r = 0.93$), $p < 0.01$, for all comparisons (Charyton et al. 2011).

## *7.7.4 Validity*

### 7.7.4.1 Discriminant Validity

In a previous study, Charyton and Snelbecker (2007) found that a music improvisation creativity measure was not related to general creativity constructs (CPS, CT, CRT), yet the Purdue Creativity Test (PCT) demonstrated a modest relationship with these general creativity measures. The CEDA demonstrated discriminant validity from these other general creativity measures (Charyton et al. 2008), like the domain-specific music improvisation creativity measure had in previous studies (Charyton 2005, 2008; Charyton and Snelbecker 2007). The general creativity measures are described as follows:

## *7.7.5 General Creativity Measures*

*CPS*: *Creative Personality Scale*. The Creativity Personality Scale (CPS) of the Adjective Checklist (ACL) (Gough 1979) was previously administered to assess creativity attributes. According to Gough (1979), aesthetic dispositions are related to creative potential. This instrument was designed as an appraisal of the self. This test was selected because it is highly regarded, reliable, and widely used as a general creativity test (Plucker and Renzulli 1999; Oldham and Cummings 1996).

*CT: Creative Temperament Scale*. The Creative Temperament Scale (Gough 1992) was adapted from the California Psychological Inventory (CPI), which was designed to assess personality characteristics and predict what people will say and do in specific contexts. Gough (1992) suggested that this measure is capable of forecasting creative attainment in various domains, both within and outside of psychology. Any domain requires skills specific to the domain, yet this measure assesses general personality qualities cutting across disciplines. The Creative Temperament Scale is one of the special-purpose scales of the CPI.

*CRT: Cognitive Risk Tolerance Survey*. The Cognitive Risk Tolerance Survey (Snelbecker, G. E., McConologue, T., & Feldman, J. M. (2001). *Cognitive risk tolerance survey.* Unpublished manuscript.) consists of 35 self-report items to assess an individual's ability to formulate and express one's ideas despite potential opposition. Responses are on a Likert scale ranging from 0 (very strongly disagree) to 9 (very strongly agree). Higher scores indicate higher levels of cognitive risk tolerance. The Cognitive Risk Tolerance Survey was developed as an extension of an earlier risk tolerance model developed by Snelbecker et al. (1989, 1990). Charyton and Snelbecker (2007a) found that the CRT measure was moderately correlated with the CPS ($r = 0.36$, $p < 0.01$) and CT ($r = 0.34$, $p < 0.01$), which were moderately related to each other ($r = 0.35$, $p < 0.01$). Cognitive risk tolerance may be a component of general creativity that is moderately related to, yet different from, other general creativity measures. This measure was selected as a distinct component of general creativity.

Discriminant validity for the CEDA was established with general creativity measures, respectively ($r = -0.01$ (CPS), $r = -0.13$ (CT), $r = -0.19$ (CRT), $p > 0.05$), suggesting that the CEDA is domain specific to engineering.

#### 7.7.5.1 Convergent Validity

Correlations between the CEDA and other engineering creativity and spatial measures were conducted to establish convergent validity. The CEDA was moderately correlated with the PCT ($r = 0.39$, $p < 0.01$) and slightly correlated with the Purdue Visualization Spatial Test–Rotations (PVST-R) ($r = 0.19$, $p < 0.05$). The CEDA, including Usefulness in the formula of assessment, demonstrated similar results. The CEDA with Usefulness was moderately correlated with the PCT ($r = 0.31$, $p < 0.01$) and slightly correlated with the PVST-R ($r = 0.21$, $p < 0.05$). These findings suggest that creative engineering design overlaps with spatial skills. This finding is logical since sketching requires spatial skills. Furthermore, in the CEDA, participants are instructed to manipulate the objects in any manner they desire without replication. In the PVST-R, participants are instructed to rotate the objects.

The relationship among the variables is consistent with the previous (or initial) CEDA scoring formula and the revised CEDA scoring formula. Figure 7.3 depicts the initial CEDA scoring and the revised CEDA scoring (new CEDA scoring in parentheses) that includes Usefulness. Other domain-specific engineering-specific measures are moderately related to the CEDA, demonstrating that the CEDA is more like other engineering creativity measures (PCT) and engineering spatial measures (PVST-R). Both are domain specific to engineering. This contrasts with previous findings, demonstrating that the CEDA was not like other general creativity measures. Thus, by directly assessing Originality and Usefulness, the CEDA assesses creativity as a well-accepted standardized definition that is also domain specific to engineering (Charyton et al. 2011).

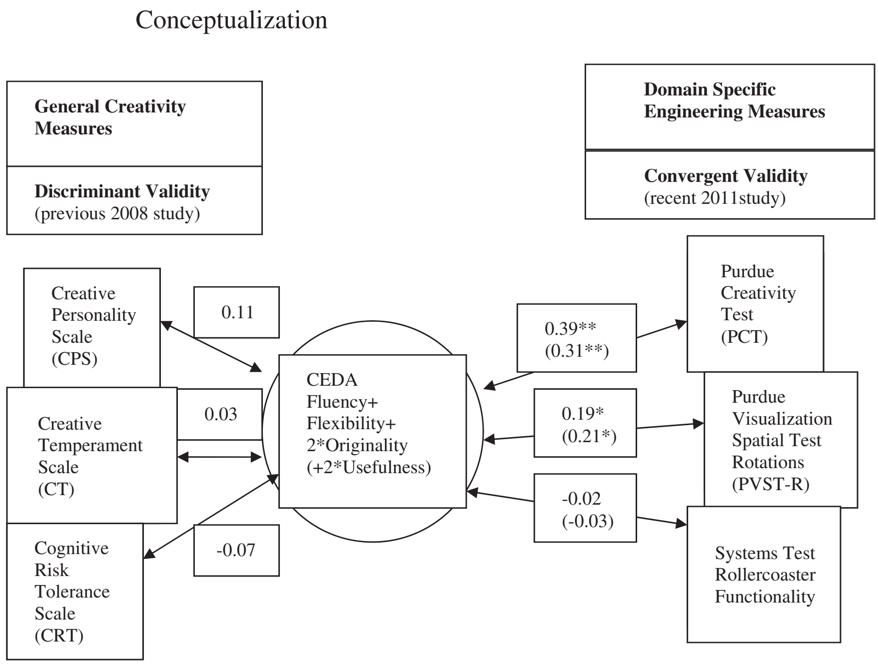


**Fig. 7.3** Conceptualization of the relationship of the Creative Engineering Design Assessment (CEDA) with general creativity measures (previous study 2008) and domain specific engineering measures (recent study 2011). The *top left* portion of the figure is based on previous research (Charyton et al. 2008), and the *top right* portion is based on current data in this study with the original and revised CEDA scoring formula. The revised scoring CEDA formula is in parentheses. The correlations for the revised formula with Usefulness (2*Usefulness added to the original CEDA formula) illustrates similar findings with the new scoring of the revised CEDA compared to the previous scoring method without Usefulness. ** indicates statistical significance at the 0.01 level * indicates statistical significance at the 0.05 level

### *7.7.6 Engineering Measures*

*PSVT-R: The Purdue Spatial Visualization Test–Rotations.* The Purdue Spatial Visualization Test–Rotations is the most common test of engineering students' spatial visualization (Carteret al. 1987). The PSVT-R consists of 30 unfamiliar objects that the observer mentally rotates and has been used for first-year engineering programs (Bodner and Guay 1997). The PSVT-R was devised to test spatial development while minimizing analytic processing (Guay 1980). Using lines and symbols to represent thoughts and ideas of engineers can be more effective than purely verbal descriptions (Scribner and Anderson 2005). The PSVT-R correlated significantly with participants' scores on spatial tasks (Kovac 1989). Males have previously performed better on PSVT questions than females (Guay 1978; Kinsey et al. 2007); however, the two genders scored equally on self-efficacy (belief in their own capabilities in order to accomplish the task), while upper-class students scored higher on both (Kinsey et al. 2007). The PSVT-R is often administered to freshmen with a course objective of assessing the spatial skills needed to succeed in subsequent engineering design graphics courses (Sorby and Baartmans 1996).

The PSVT-R has high construct validity for spatial visualization ability (Branoff 2000; Guay 1980). Guay reports internal consistency (reliability) (Kuder Richardson $r = 0.87$, 0.89, and 0.92) from 217 university students, 51 skilled machinists, and 101 university students, respectively (Guay 1980). Other studies also report high reliability (Kuder Richardson $r = 0.80$ or higher) (Branoff 2000; Scribner and Anderson 2005). Based on these analyses, most researchers agree that the PSVT is a good measure of spatial ability (Branoff 2000; Yue and Chen 2001).

The CEDA is useful for assessing creativity in Science, Technology, Engineering and Mathematics (STEM). Constructs such as general creativity and cognitive risk tolerance can also be assessed in STEM disciplines (Charyton and Snelbecker 2007; Charyton et al. 2011). These dimensions may contribute toward a richer understanding of creative design specific to engineering.

## 7.8 Importance of Creative Engineering Design to STEM (Science, Technology, Engineering and Mathematics) Prevails

"Our country's economic competitiveness and prosperity depend on innovative STEM-educated young people that work together to solve our problems effectively and creatively" (Brower et al. 2007). According to these authors, educators need to engage at least 70 % of the student population not just the top 10 % of students. Students entering STEM are a current vital need, not only for our country, but for many countries. If students are taught that engineering can be fun through creative design, this could potentially engage more students to pursue engineering and may result in increased recruitment and retention in the colleges of engineering.

Highly creative people redefine problems, analyze ideas, persuade others, and take reasonable risks to help generate ideas (Sternberg 2001). Creativity is certainly among the most important human activity that provides conveniences and products of human inventiveness (Simonton 2000). Despite its importance to society, creativity has received relatively little attention in psychology compared to other research topics (Feist 1999; Sternberg and Lubart 1999). Although people have been engaged for centuries in creativity, only in the past few decades has this process been considered capable of analysis and improvement (Soibelman and Peña-Mora 2000). More recently, there is growing interest and need for creativity in the sciences.

Currently, creativity and critical thinking skills are incorporated into the core mission statement of many universities, educational programs, and college curriculum. However, few institutions utilize an empirical method of evaluating creativity. The published literature also suggests that creativity is likely domain specific (Kaufman and Baer 2005). Even in similar science or STEM areas such as engineering and chemistry—creativity may be expressed specifically and uniquely in each area.

## 7.9 Creativity for Increasing Enrollment in STEM

Creative design and its measurement may act as a catalyst to increase enrollment in STEM. Exposure to engineering and the CEDA may likely take place in universities, colleges, community colleges, institutes, academies, high schools, and junior high schools. The CEDA was developed to measure creative engineering design in adolescent students. In regard to "gifted" children, if the child is reading at the 8th grade level, then the CEDA may also be appropriate at younger chronological ages.

Creating an interest in STEM has become the new frontier (Harriger et al. 2008). Competitive degree programs require creativity and innovation (Harriger et al. 2008). STEM interests can also be heightened by establishing the relationship between creative and performing arts with broader STEM concepts (Reflections and Measures of STEM Teaching and Learning on K-12 Creative and Performing Arts Students). Harriger (2008) suggests that designing rock guitars was successful for engaging high school students. The CEDA includes a problem to create designs that produce sound that could be useful in early STEM curricula.

Creativity is also a universal application of innovativeness that does not show favoritism toward race or ethnic boundary (Riffe 1985) nor gender. Underrepresented students' interests and performance are needed to foster skills that are prerequisites for STEM careers (Verma 2011). The CEDA has been administered to men and women of various racial and ethnic backgrounds and is suitable for diverse populations.

Since 2005, the USA has been following with job creation (at 11th in the world) (Ireland, Belgium, and Australia are the top three, respectively); however, it has been leading with innovation and the global economy (#1 in the world) (Florida 2005). Through prioritizing creativity and innovation, as we did with prioritizing scientific creativity in the 1950s, we can enhance global prosperity, not only for the USA but also for other countries. Creativity is needed, even more, especially due to our current global and societal problems. Creativity and innovation are primarily relevant today in our current global economy and societal concerns.

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