



## Multidimensional Assessment of Creativity in an Introduction to Engineering Design Course

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## Abstract

Creative thinking includes the capacity to combine or synthesize existing ideas, images, or expertise in original ways and the experience of thinking, reacting, and working in an imaginative way characterized by a high degree of innovation, divergent thinking, and risk taking.<sup>1</sup> If we are to produce engineers who can solve society's most pressing technological problems we must provide our students with opportunities to exercise and augment their natural creative abilities and we must create classroom environments that make these exercises effective.<sup>2-4</sup> This paper will describe in detail how a second semester cornerstone (and pillar) course (Introduction to Chemical, Food, and Environmental Engineering Design) for these undergraduate degrees at *Universidad de las Américas Puebla* (Mexico) is helping to achieve these objectives, as well as its alignment with the *Investment Theory of Creativity* (ITC) developed by Sternberg and Lubart.<sup>5-8</sup>

Creativity assessment was grounded on the *Consensual Assessment* Technique that is based on the idea that the best measure of creativity regardless of what is being evaluated, is the assessment by experts in that field.<sup>9</sup> The two major projects from this course were presented to experts in the field that assessed student creative thinking by means of a rubric adapted from ITC, which provides a multidimensional assessment of creativity.<sup>6-8</sup> Possible performance levels were from *exemplar* (value of 4) to *benchmark* (value of 1). Additionally projects were assessed using the *Creative Thinking VALUE* Rubric that is made up of a set of attributes that are common to creative thinking across disciplines.<sup>1, 10</sup> Possible performance levels were entitled *capstone* or *exemplar* (value of 4), *milestones* (values of 3 or 2), and *benchmark* (value of 1).

Mean values from *Creative Thinking VALUE Rubric* assessment of two major projects from the studied course were close to the highest milestone performance level. In general, mean values from *ITC Rubric* assessment of two major projects from the studied course were at an intermediate level of performance and even lower for the product itself, which in these cases are the two designed products for corresponding projects. The vast majority of students attained projects' expected outcomes at an intermediate level. Therefore, it is suggested to further integrate creativity in subsequent pillar courses in order to foster meaningful development of Chemical, Food, and Environmental Engineering students' creative thinking.

## Introduction

Creative thinking includes the capacity to combine or synthesize existing ideas, images, or expertise in original ways and the experience of thinking, reacting, and working in an imaginative way characterized by a high degree of innovation, divergent thinking, and risk taking.<sup>1</sup> If we are to produce engineers who can solve society's most pressing technological problems we must provide our students with opportunities to exercise and augment their natural creative abilities and we must create classroom environments that make these exercises effective.<sup>2-4</sup>

### A confluence model of creativity

The confluence model of creativity (Figure 1) developed by Sternberg and Lubart<sup>6-8</sup> is based on the *Investment Theory of Creativity* (ITC) proposed by the same authors, which suggests that creativity is a decision, the decision of how and when to use one resource or the other is the most important source of individual differences. Sternberg and Lubart point out that according to ITC, creativity requires a confluence of six distinct but interrelated resources: intellectual skills, knowledge, thinking styles, personality, motivation, and environment. According to ITC, creative people are ones who are willing and able to metaphorically buy low and sell high in the realm of ideas. Buying low means pursuing ideas that are unknown or out of favor, but that have growth potential. Often, when these ideas are first presented, they encounter resistance. The creative individual persists in the face of this resistance, and eventually sells high, moving on to the next new, or unpopular, idea. In other words, such an individual acquires the creativity habit. According to these authors, major creative contributions generally begin with undervalued ideas.<sup>6-8</sup>

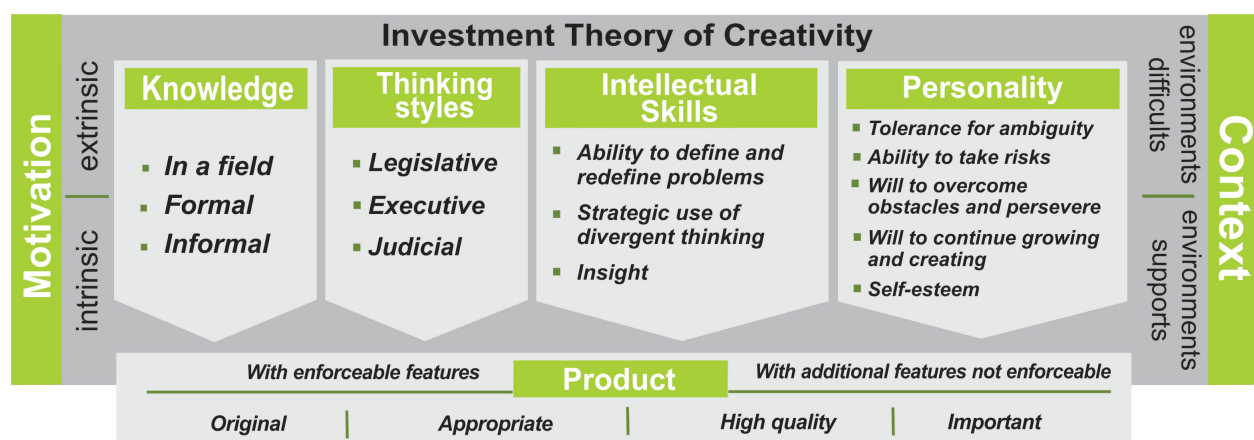


Figure 1. A confluence model of creativity (created out of Sternberg and Lubart<sup>8</sup>).

Creativity involves the application of these six resources to specific tasks:

1. *Intellectual skills.* Three intellectual skills are particularly important: (a) the synthetic skill to see problems in new ways and to escape the bounds of conventional thinking, (b) the analytic skill to recognize which of one's ideas are worth pursuing and which are not, and (c) the practical-contextual skill to know how to persuade others of (to sell other people on) the value of one's ideas. The confluence of these three skills is very important.
2. *Knowledge.* On the one hand, one needs to know enough about a field to move it forward. One cannot move beyond where a field is if one does not know where it is. On the other hand, knowledge about a field can result in a closed and entrenched perspective, resulting in a person's not moving beyond the way in which he or she has seen problems in the past. Knowledge thus can help, or it can hinder creativity.
3. *Thinking styles.* Thinking styles are preferred ways of using one's skills. In essence, they are decisions about how to deploy the skills available to a person. With regard to thinking styles, a legislative style is particularly important for creativity, that is, a preference for thinking and a decision to think in new ways. It also helps to become a major creative thinker, if one is able to think globally as well as locally, distinguishing the forest from the trees and thereby recognizing which questions are important and which ones are not.
4. *Motivation.* Intrinsic, task-focused motivation is also essential to creativity. The research of Amabile and others has shown the importance of such motivation for creative work and has suggested that people rarely do truly creative work in an area unless they really love what they are doing and focus on the work rather than the potential rewards.<sup>9, 12-14</sup>
5. *Personality.* Numerous research investigations have supported the importance of certain personality attributes for creative functioning. These attributes include, but are not limited to, willingness to overcome obstacles, willingness to take sensible risks, willingness to tolerate ambiguity, and self-efficacy. In particular, buying low and selling high typically means defying the crowd, so that one has to be willing to stand up to conventions if one wants to think and act in creative ways. Often creative people seek opposition; that is, they decide to think in ways that countervail how others think. Note that none of the attributes of creative thinking is fixed. One can decide to overcome obstacles, take sensible risks, and so forth.
6. *Environment.* Finally, one needs an environment that is supportive and rewarding of creative ideas. One could have all of the internal resources needed to think creatively, but without some environmental support (such as a forum for proposing those ideas), the creativity that a person has within him or her might never be displayed.<sup>6-8, 11</sup>

## Context

Recently *Universidad de las Américas Puebla* generated new curricula for its undergraduate degrees in chemical (CE), food (FE), and environmental engineering (EE). These new “integrated and spiral” curricula includes seven departmental courses considered chemical, food,



and environmental engineering “pillars”, which major goal is to enhance the development of the broad range of so-called 21st century expertise in CE, FE, and EE students by designing critical support systems. Pillar courses are being designed taking into account technological advances and recent research on human learning and cognitive processes that underlie expert performances.

Using the *Framework for 21st Century Learning*<sup>15-17</sup> and guidelines from research on *How People Learn*<sup>18, 19</sup> we are defining the standards for chemical, environmental, and food engineering 21st century expertise; creating formative and summative assessments to evaluate student attainment of 21st century expertise; designing instruction activities that promote 21st century expertise; developing professional development opportunities for “pillar” course instructors; and generating corresponding learning environments that promote 21st century expertise in these courses. By means of Tablet PCs and associated technologies high-quality learning environments are being created to promote an interactive classroom while integrating multiple formative assessments. Nowadays the standards for chemical, environmental, and food engineering 21st century expertise include *Core Engineering Subjects* and *21st Century Themes* (such as global awareness, financial, economic, business and entrepreneurial literacy, civic literacy, health literacy, and environmental literacy), *Learning and Innovation Skills* (such as creativity and innovation, critical thinking and problem solving, and communication and collaboration), *Information, Media and Technology Skills* (such as information literacy, media literacy, and information, communications and technology literacy), and *Life and Career Skills* (such as flexibility and adaptability, initiative and self-direction, social and cross-cultural skills, productivity and accountability, leadership and responsibility) as proposed by the Partnership for 21st Century Skills.<sup>15-17</sup>

This paper describes in detail how a second semester cornerstone (and pillar) course (*Introduction to Chemical, Food, and Environmental Engineering Design*) for CE, FE, and EE is helping students to develop their creativity, as well as its alignment with the *Investment Theory of Creativity* developed by Sternberg and Lubart.<sup>5-8</sup> As stated previously, ITC comprises six resources for creativity: intellectual processes, knowledge of domain, intellectual style, personality, motivation, and environmental context. Creative performance ensues from a confluence of these six elements.<sup>6-8</sup> *Introduction to Chemical, Food, and Environmental Engineering Design* is a 3 credit required course for CE, FE, and EE. Course content and classroom activities are divided into two, 75-minute sessions (Concepts, and Laboratory) per week. Students have three different facilitators (an instructor and two teaching assistants). Course main goal is to introduce students to the Engineering Method, this is accomplished by focusing on six course objectives: self-regulation, communication, working cooperatively and collaboratively, problem solving, modeling, and quality. *Introduction to Chemical, Food, and Environmental Engineering Design* uses active, collaborative and cooperative learning

techniques; course structure and its alignment to the confluence model of creativity of Sternberg and Lubart<sup>8</sup> is displayed in Figure 2.

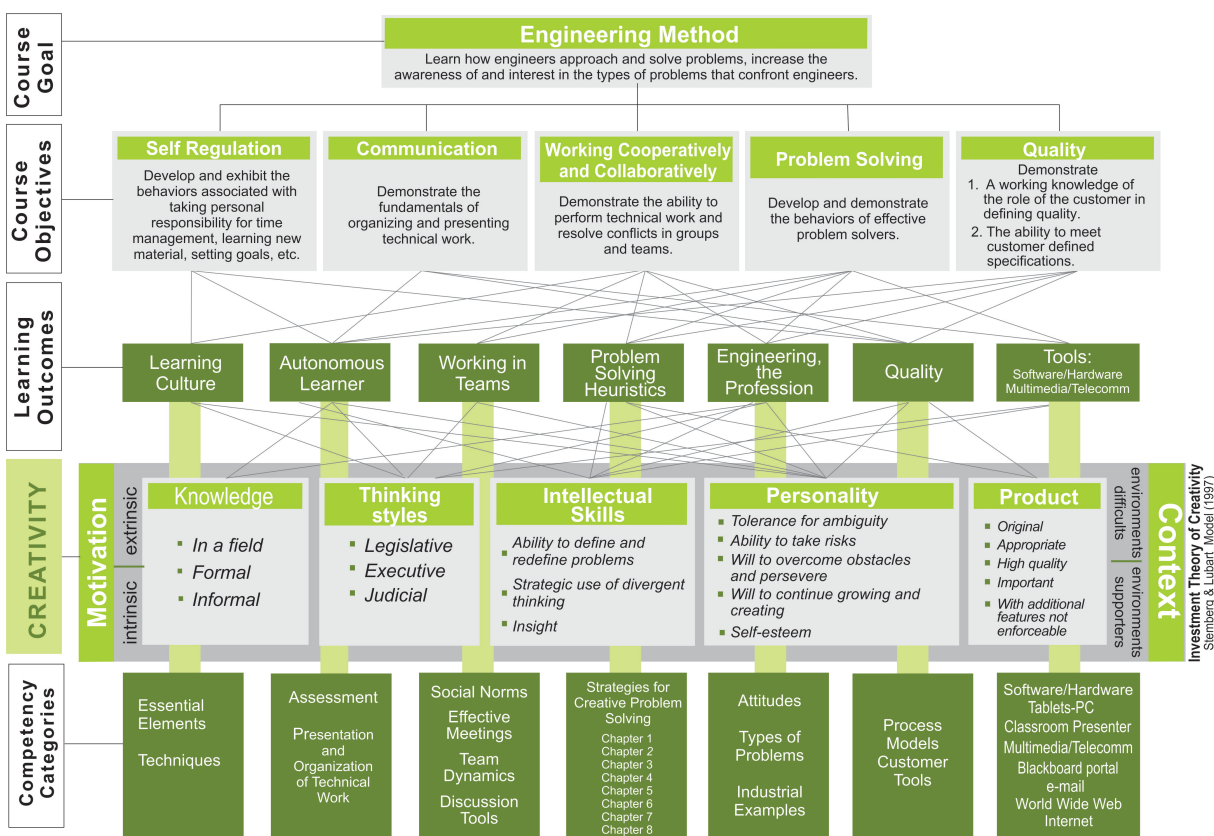


Figure 2. Introduction to Chemical, Food, and Environmental Engineering Design course structure and its alignment to the confluence model of creativity of Sternberg and Lubart.<sup>8</sup>

“Concepts” (Figure 3) introduce students to the engineering design process, problem-solving techniques, working in teams, engineering as a profession, and planning for success that students then apply in “Laboratory” (Figure 4) on two actual design projects. Students were organized into multidisciplinary teams of three to four members; the group had a total of thirty-eight students (15 male). The “Concepts” section uses quizzes given in nearly every session to ascertain whether students have understood the material in their pre-class reading assignments. In addition, we encourage students to write brief reflective journal entries to further solidify and reinforce their own understanding, as well as demonstrate that improved understanding for an improved quiz grade. *Universidad de las Américas Puebla’s* Chemical, Environmental, and Food engineering students have in the studied course a great opportunity for a multidisciplinary collaborative experience.

Creativity is an integral part of the studied course; CE, FE, and EE students are exposed to a wide number of ideas to develop their creativity while enhancing their problem solving abilities. The use of real-world examples and two major projects allow students to directly apply the suggested problem solving heuristic, which is the backbone of one of the textbooks for the course (*Strategies for Creative Problem Solving* by Fogler, LeBlanc, and Rizzo<sup>20</sup>).

CONCEPTS SESSION								
Self-control	Return TABLET PC							
Activity	Preparing for Concepts session Advanced reading	<b>CONCEPTS session begins</b>  <b>QUIZ</b> Corresponding Topic	<b>SIGN ATTENDANCE</b>  GET ASSESSED DESIGN BLINDER	<b>Mini lecture</b> Concepts examples and solved cases	<b>SUBMIT PREVIOUS WEEK HOMEWORK AND CORRECTIONS</b>	<b>Cooperative and collaborative learning</b>	<b>ROLE ASSIGNMENT AND HOMEWORK ALLOCATING</b>	<b>Session ending</b>
Strategies		<b>Dynamic</b> Student gets Tablet PC, answers the QUIZ, recives feedback in real-time		<b>Dynamic</b> Tablet PC and Classroom Presenter clarify doubts, provides feedback in real-time		<b>Dynamic</b> Pair reading oral presentations intra-team and inter-team exercises		<b>Dynamic</b> Facilitator briefly presents next concepts session and motivates students to improve their products
Self-management Blackboard portal	Download the reading	Find the quiz	Download class presentation	Follow class presentation	Use of electronic resources	Download lab homework	Check grades Download assessment rubrics	End Blackboard session
Homework	<b>Reading</b> Corresponding topic						<b>SUBMIT DESIGN BINDER</b>	
Self-regulation Optional homework			<b>QUIZ Corrections</b>  Engineering journal		Check the assessment performed by facilitators to design binder		Lab homework meeting  Meeting minutes	

Figure 3. *Introduction to Chemical, Food, and Environmental Engineering Design* concepts session didactical structure as well as teaching and learning strategies.

LABORATORY SESSION								
Self-control	Return TABLET PC							
Activity	<b>TEAM SELF-ASSESSMENT OF DESIGN BINDER</b>	<b>LABORATORY session begins</b>  <b>Mini lecture</b> Activities description and tools' demonstration	<b>SIGN ATTENDANCE</b>  SUBMIT QUIZ CORRECTIONS	<b>Peer assessment</b>	<b>ROLE ASSIGNMENT FOR CLASS ACTIVITIES</b> Class activities minutes	<b>Cooperative and collaborative learning</b>	<b>ROLE ASSIGNMENT AND HOMEWORK ALLOCATING</b>	<b>Session ending</b>
Strategies		<b>Dynamic</b> Tools' availability Support if team requires it		<b>Dynamic</b> Submit design binder for peer assessment  Aplication of learned techniques, information, management, etc.		<b>Dynamic</b> Project development lab experiments modeling and design prototype		<b>Dynamic</b> Facilitator briefly presents next lab session and motivates students to improve their assessments
Self-management Blackboard portal	Upload engineering Journal		Download class presentation			Download concepts Homework	Check grades Download assessment rubrics	End Blackboard session
Homework	Arrange the design binder for peer assessment						Team Homework	
Self-regulation Optional Homework	Meeting to prepare design binder		Research about the topic		Individual homework Quiz and Journal		Prototype homework meeting  Meeting minutes	

Figure 4. *Introduction to Chemical, Food, and Environmental Engineering Design* laboratory session didactical structure as well as teaching and learning strategies.

## ***Introduction to Chemical, Food, and Environmental Engineering Design two major projects***

### *First project (thermodynamics and heat transfer): Save the Penguins*

At the University of Virginia, Larry Richards and his colleagues have undertaken a major challenge to design, implement, test and distribute Engineering Teaching Kits (ETKs). In particular, the *Save the Penguins* ETK is a design-based science curriculum, in which students are challenged to create a dwelling that reduces heat transfer in order to keep a penguin-shaped ice cube from melting.<sup>21</sup> This curriculum was originally developed by engineering students and faculty at the University of Virginia as part of the *Virginia Middle School Engineering Education Initiative*, but was subsequently revised and re-written by Schnittka after pilot testing.<sup>22</sup> Then it has been utilized by many others (including ourselves<sup>23</sup>) in several countries.

The *Save the Penguins* ETK is designed to address student alternative conceptions about heat, heat transfer, and temperature, increase student interest in science, and give students the opportunity to learn more about engineering through the engineering design process. The *Save the Penguins* ETK is described in detail elsewhere.<sup>21-23</sup> In our case, the entire ETK took six class blocks to complete. In brief, it began with the teacher performing some engaging demonstrations about heat transfer. In these demonstrations, the teacher modeled the experimental methods as the “more knowledgeable other,” and students were shown how to undertake these methods on their own in teams.<sup>21</sup> The teacher then elicited discussions and reflections on the discrepant events students witness as s/he and the students “talked science.” The teacher described how experiments are conducted with controls and a variable, and got students to identify the independent and dependent variables and the controls. The teacher introduced the concept of heat by first finding out what students thought about it. Then presented the concepts of conduction, convection, and radiation, and performed additional demonstrations illustrating the three methods of heat transfer.<sup>23</sup> These demonstrations are designed to provide discrepant events, challenging students’ conceptions of heat transfer. The seven demonstrations are designed to consume one class period out of the six class periods. Students were then presented with the design challenge: to build a structure that will keep a penguin-shaped ice cube from melting. They were given selected materials (with different costs), and instructed to perform experiments to test these different materials before using them, designing, and building the dwelling for their ice penguin. Students worked in teams of 3 or 4 students each to test materials, design the dwelling, test the dwelling, and create a design binder explicating their progress, design decisions, materials used, and final design. Teams tested their first iteration of the design and shared their results, their conception of what worked well and what did not, with the class. Students used the ideas and suggestions from their peers to re-design their structure with the goal of improving its performance. They had multiple opportunities to construct, test, and revise their work. The team that constructed the dwelling of lesser cost that kept the most of the ice penguin mass won the competition.

Students learned about heat, temperature, controls and variables in experimental methodology, insulators and conductors, and other material properties as they assembled the dwelling for their penguin ice cube.<sup>21</sup> The final design challenge (competition) took place on the sixth and last day of the unit. After having the opportunity to redesign their dwelling, each team again started with a 10 g ice penguin. After 20 minutes in the test, students once again removed their ice penguin and found the mass of their remaining ice. They then finalized the design binder they have been working on, so that it completely described the design process for the entire activity. The class as a whole discussed how they think certain materials may have contributed to or hindered heat transfer, how much ice melted during the two challenges, and how modifications to their design may have affected the final outcomes. The class discussed why some designs were more successful than others in preventing heat transfer.

### *Second project (packaging design and strength of materials): Potato Chip Challenge*

The *Potato Chip Challenge*<sup>24</sup> from Wondergy is an engineering challenge that has students designing a package to protect a potato chip being sent through the mail. In order to win, the crunchy snack food must arrive at its destination intact and undamaged. Single regular-type potato chips are mailed by teams that create a potato chip package for mailing. Another team receives the chip and scores their received chip based on standard criteria. In our case, instead of mailing the package, it was subjected to three standard tests for food packaging. The *Potato Chip Challenge* is described in detail elsewhere.<sup>24, 25</sup>

No substance could be applied to the chip, or the chip altered in any way. The chip had to be recoverable and edible (though they weren't eaten) when received by the evaluating team. Students worked in teams on the design, building and testing of this project package. No pre-made packages could be used (such as a Pringles can or a pre-molded plastic container). Packages were limited in size to 3" x 5". In our case, the entire *Potato Chip Challenge* took five class blocks to complete. The final design challenge (testing of packages with single chips) took place on the last day of the unit. They then finalized the design binder they have been working on, so that it completely described the design process for the entire activity. The team that constructed the packaging of smallest mass that kept the chip most intact won the competition.

### **Assessment of creativity**

Creativity assessment was grounded on the *Consensual Assessment Technique*<sup>9</sup>, which is based on the idea that the best measure of creativity regardless of what is being evaluated, is the assessment by experts in that field. The two major projects from the studied course were presented to a group of twenty experts in the field (chemical, food, and environmental engineering professors that teach engineering design capstone courses and alumni with such expertise) that assessed student creative thinking by means of a rubric adapted from the

*Investment Theory of Creativity* (ITC), which provides a multidimensional assessment of creativity.<sup>6-8</sup> Possible performance levels were from *exemplar* (value of 4) to *benchmark* (value of 1).

Additionally projects were assessed using the *Creative Thinking VALUE Rubric* (Appendix A), which is made up of a set of attributes that are common to creative thinking across disciplines. Possible performance levels were entitled *capstone* or *exemplar* (value of 4), *milestones* (values of 3 or 2), and *benchmark* (value of 1).<sup>1, 10</sup> Evaluators were further encouraged to assign a value of zero if work did not meet *benchmark* level performance. Instructor, peer-, and self-assessments were also performed throughout the course on several assignments (formative) as well as on two major projects (summative).

## Results and discussion

Mean values from *Creative Thinking VALUE Rubric* assessment of two major projects from the course *Introduction to Chemical, Food, and Environmental Engineering Design* were 3.10 for *Acquiring Competencies* (attaining strategies and skills within a particular domain), 3.10 for *Taking Risks* (may include personal risk, fear of embarrassment or rejection, or risk of failure in successfully completing assignment, i.e. going beyond original parameters of assignment, introducing new materials and forms, tackling controversial topics, advocating unpopular ideas or solutions), 3.30 for *Solving Problems* (developing a logical, consistent plan to solve the problem, recognizing consequences of solution and articulating reason for choosing proposed solution), 2.60 for *Embracing Contradictions* (integrating alternate, divergent, or contradictory perspectives or ideas), 2.50 for *Innovative Thinking* (novelty or uniqueness of idea, claim, question, form, etc.), and 3.20 for *Connecting, Synthesizing, and Transforming* (transforming ideas or solutions into entirely new forms).

Mean values from *Investment Theory of Creativity Rubric* (created out of Sternberg and Lubart<sup>8</sup>) assessment of two major projects from the studied course were 3.00 for *creative performance*, 3.44 for *motivation* that incorporates level of commitment, project pride, and interest in task (Figure 5), 3.00 for *intellectual style* that includes indicators such as autonomy and rules (Figure 6), 3.25 for *creative personality* with indicators such as tolerance for ambiguity, risk taking, will, and perseverance (Figure 7), 3.00 for *knowledge of domain* that comprises application of formal and informal knowledge (Figure 8), 3.33 for *intellectual processes* which includes indicators such as sensitivity, problem identification, ideation, ability to recognize ideas that have potential to be valued, as well as ability to sell your ideas effectively and persuade of its value (Figure 9), and 2.38 for the *creative product* itself, which includes its originality, quality, importance, and feasibility (Figure 10) that in this case are the two designed products for corresponding two major course projects.

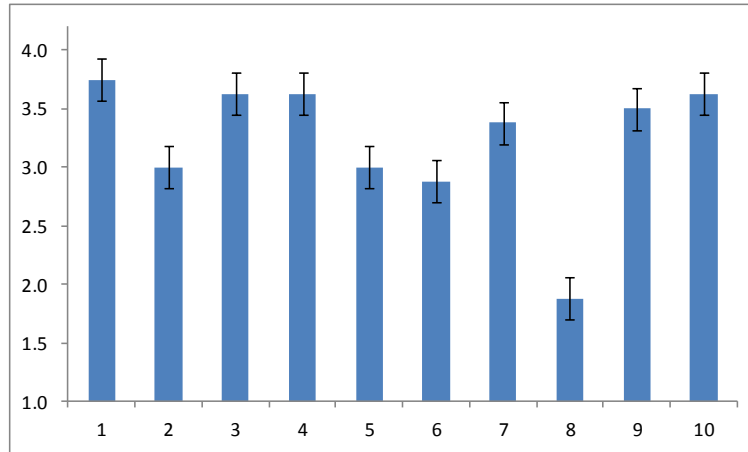


Figure 5. Teams' (each bar represents a different team) **motivation** average scores and standard deviations (error bars) assessed by means of the *Investment Theory of Creativity Rubric* created out of Sternberg and Lubart.<sup>8</sup>  
Performance levels on the y-axis vary from *exemplar: 4* to *benchmark: 1*.

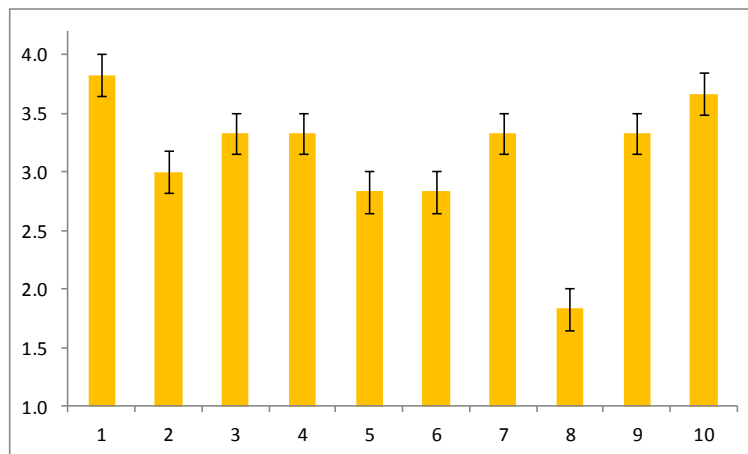


Figure 6. Teams' (each bar represents a different team) **intellectual styles** average scores and standard deviations (error bars) assessed by means of the *Investment Theory of Creativity Rubric* created out of Sternberg and Lubart.<sup>8</sup>  
Performance levels on the y-axis vary from *exemplar: 4* to *benchmark: 1*.

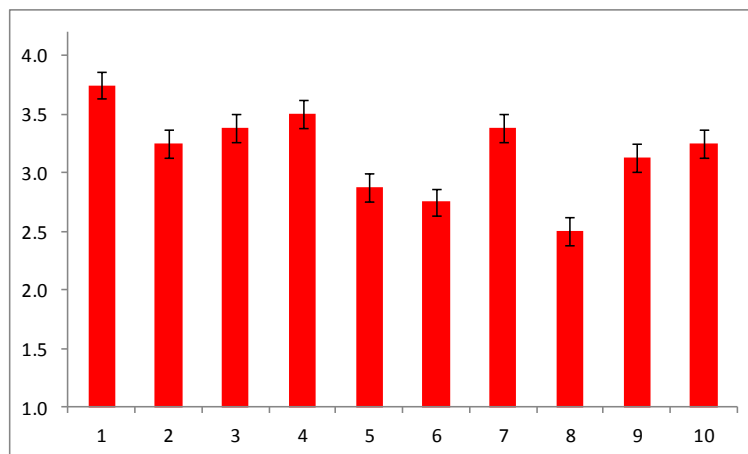


Figure 7. Teams' (each bar represents a different team) **creative personality** average scores and standard deviations (error bars) assessed by means of the *Investment Theory of Creativity Rubric* created out of Sternberg and Lubart.<sup>8</sup>  
Performance levels vary from *exemplar: 4* to *benchmark: 1*.

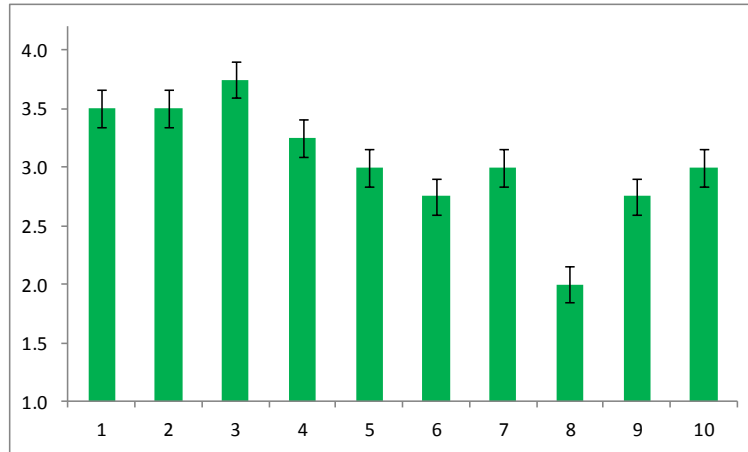


Figure 8. Teams' (each bar represents a different team) **knowledge of domain** average scores and standard deviations (error bars) assessed by means of the *Investment Theory of Creativity Rubric* created out of Sternberg and Lubart.<sup>8</sup> Performance levels on the y-axis vary from *exemplar*: 4 to *benchmark*: 1.

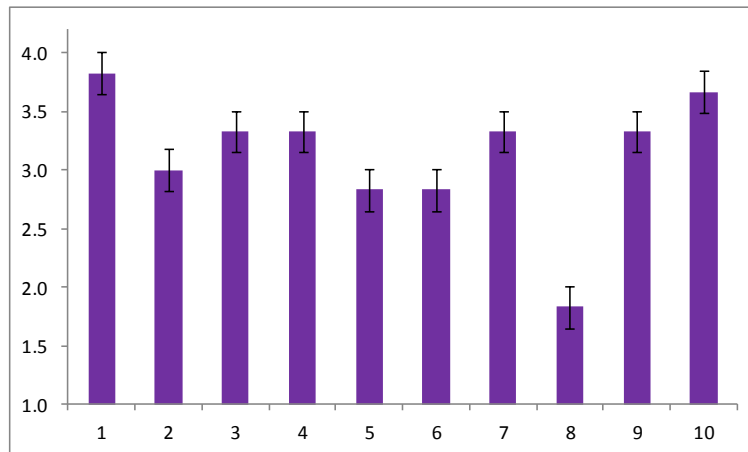


Figure 9. Teams' (each bar represents a different team) **intellectual processes** average scores and standard deviations (error bars) assessed by means of the *Investment Theory of Creativity Rubric* created out of Sternberg and Lubart.<sup>8</sup> Performance levels on the y-axis vary from *exemplar*: 4 to *benchmark*: 1.

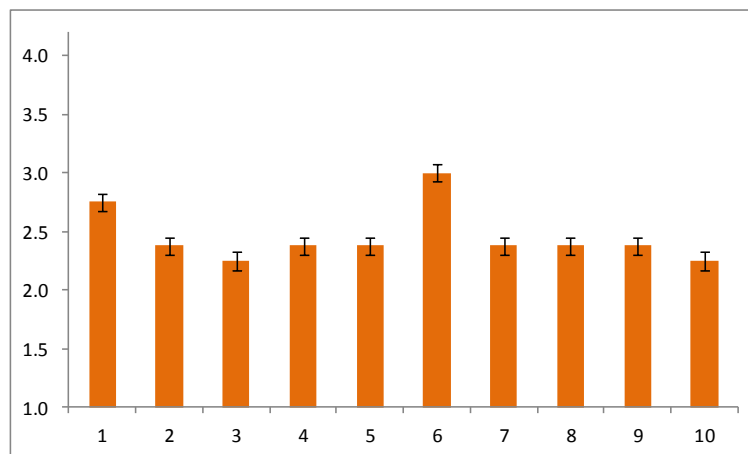


Figure 10. Teams' (each bar represents a different team) **creative product** average scores and standard deviations (error bars) assessed by means of the *Investment Theory of Creativity Rubric* created out of Sternberg and Lubart.<sup>8</sup> Performance levels on the y-axis vary from *exemplar*: 4 to *benchmark*: 1.



Data from the *Investment Theory of Creativity Rubric* assessment of two major projects from the course *Introduction to Chemical, Food, and Environmental Engineering Design* were further analyzed by a two-way ANOVA; there were significant differences ( $p < 0.05$ ) among means between teams as well as between evaluated criteria. To visually compare studied teams on assessed criteria, Figure 11 presents the average values obtained regarding each ITCR assessed criterion for studied teams; it can be observed that team number eight consistently obtained lower scores, being significantly ( $p < 0.05$ ) different from the other teams (Figure 12). Final grades of two students from team eight were the lowest of the course as well as for the concepts session (individual part of the course). This team was originally a four-member team but one student withdrew from the course at mid-term.

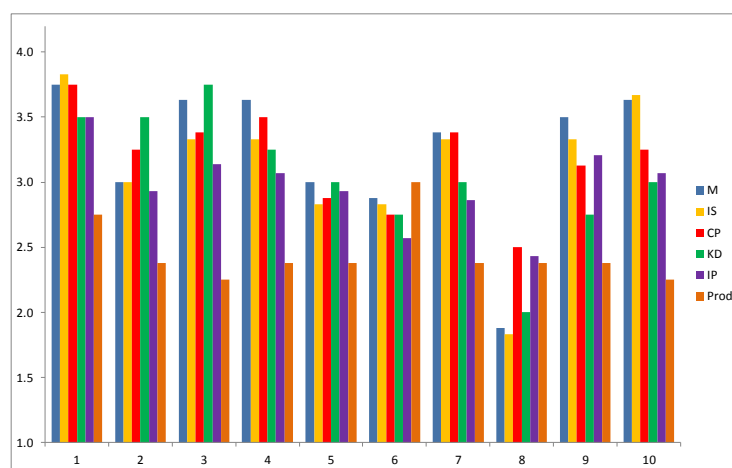


Figure 11. Teams' (numbered 1 to 10) average scores (M: motivation, IS: intellectual style, CP: creative personality, KD: knowledge of domain, IP: intellectual processes, and Prod: creative product) assessed by means of the *Investment Theory of Creativity Rubric* created out of Sternberg and Lubart.<sup>8</sup> Performance levels on the y-axis vary from *exemplar*: 4 to *benchmark*: 1.

Furthermore, the creative product (Prod) received significantly ( $p < 0.05$ ) lower scores than the other evaluated criteria (Figure 12). This could be due to the restrictions posted for each one of the two tested major projects. Thus, the experts may have evaluated the creative product itself stricter than the other criteria.

In general, students' creative thinking (Figure 13) was at an intermediate level in both the capacity to combine or synthesize existing ideas or expertise in original ways and the experience of thinking, reacting, and working in an imaginative way. Scores between 2 (milestones lower level of performance) and 3 (milestones higher level of performance) were assigned for the majority of teams.

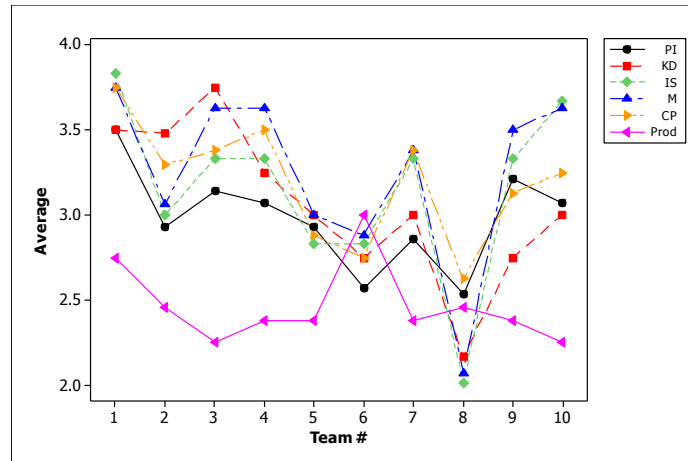


Figure 12. Interaction plot for evaluated criteria (M: motivation, IS: intellectual style, CP: creative personality, KD: knowledge of domain, PI: intellectual processes, and Prod: creative product) assessed by means of the *Investment Theory of Creativity Rubric* created out of Sternberg and Lubart.<sup>8</sup> Performance levels on the y-axis vary from *exemplar*: 4 to *benchmark*: 1.

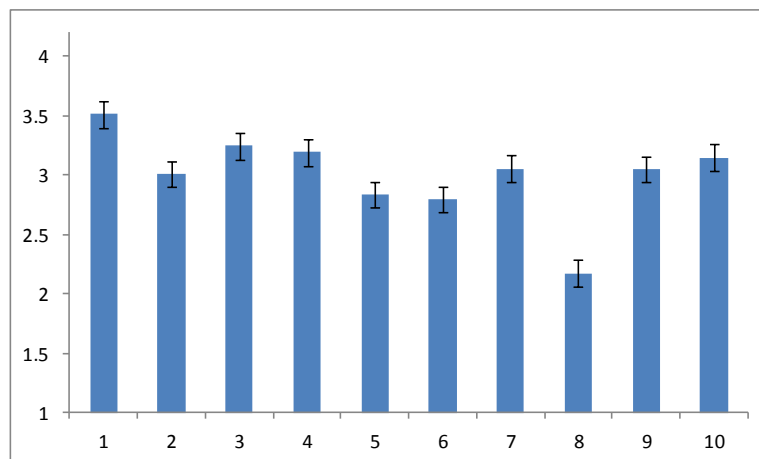


Figure 13. Creative thinking average team (each bar represents a different team) scores and standard deviations (error bars) assessed by means of the *Investment Theory of Creativity Rubric* created out of Sternberg and Lubart.<sup>8</sup> Performance levels on the y-axis vary from *exemplar*: 4 to *benchmark*: 1.

The vast majority of the teams were able to attain projects' expected outcomes at an intermediate level. Therefore, it is suggested to further integrate creativity in subsequent pillar courses in order to foster meaningful development of students' creative thinking. Furthermore, reflections integrated in the two projects' design binders, suggest that these projects allowed students to strengthen their learning and understanding of key concepts regarding course learning outcomes, expand their notion of the engineering design processes and link this knowledge to real life examples (these reflections are not part of this research and will not be presented here).

## Final Remarks

The results achieved by students in the course *Introduction to Chemical, Food, and Environmental Engineering Design* demonstrate that creativity assessment is not an easy task, but the applied rubrics allowed us to evaluate not only the final product of a creative process, but several important aspects during this creative process. Assessed rubrics allowed the identification of several opportunity areas to improve the studied engineering cornerstone course. With sights set on this, additional didactic interventions are needed to further enhance creative thinking, make the design processes more efficient, as well as to overall improve the creative experience for students in this second semester cornerstone course.

## Acknowledgments

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## Appendix A\*

### CREATIVE THINKING VALUE RUBRIC

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The VALUE rubrics were developed by teams of faculty experts representing colleges and universities across the United States through a process that examined many existing campus rubrics and related documents for each learning outcome and incorporated additional feedback from faculty. The rubrics articulate fundamental criteria for each learning outcome, with performance descriptors demonstrating progressively more sophisticated levels of attainment. The rubrics are intended for institutional-level use in evaluating and discussing student learning, not for grading. The core expectations articulated in all 15 of the VALUE rubrics can and should be translated into the language of individual campuses, disciplines, and even courses. The utility of the VALUE rubrics is to position learning at all undergraduate levels within a basic framework of expectations such that evidence of learning can be shared nationally through a common dialog and understanding of student success.

#### Definition

Creative thinking is both the capacity to combine or synthesize existing ideas, images, or expertise in original ways and the experience of thinking, reacting, and working in an imaginative way characterized by a high degree of innovation, divergent thinking, and risk taking.

#### Framing Language

Creative thinking, as it is fostered within higher education, must be distinguished from less focused types of creativity such as, for example, the creativity exhibited by a small child's drawing, which stems not from an understanding of connections, but from an ignorance of boundaries. Creative thinking in higher education can only be expressed productively within a particular domain. The student must have a strong foundation in the strategies and skills of the domain in order to make connections and synthesize. While demonstrating solid knowledge of the domain's parameters, the creative thinker, at the highest levels of performance, pushes beyond those boundaries in new, unique, or atypical recombinations, uncovering or critically perceiving new syntheses and using or recognizing creative risk-taking to achieve a solution.

The Creative Thinking VALUE Rubric is intended to help faculty assess creative thinking in a broad range of transdisciplinary or interdisciplinary work samples or collections of work. The rubric is made up of a set of attributes that are common to creative thinking across disciplines. Examples of work samples or collections of work that could be assessed for creative thinking may include research papers, lab reports, musical compositions, a mathematical equation that solves a problem, a prototype design, a reflective piece about the final product of an assignment, or other academic works. The work samples or collections of work may be completed by an individual student or a group of students.

#### Glossary

*The definitions that follow were developed to clarify terms and concepts used in this rubric only.*

- Exemplar: A model or pattern to be copied or imitated (quoted from [www.dictionary.reference.com/browse/exemplar](http://www.dictionary.reference.com/browse/exemplar)).
- Domain: Field of study or activity and a sphere of knowledge and influence.

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#### Definition

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*Evaluators are encouraged to assign a zero to any work sample or collection of work that does not meet benchmark (cell one) level performance.*

	Capstone 4	Milestones 3                      2		Benchmark 1
<b>Acquiring Competencies</b> <i>This step refers to acquiring strategies and skills within a particular domain.</i>	Reflect: Evaluates creative process and product using domain-appropriate criteria.	Create: Creates an entirely new object, solution or idea that is appropriate to the domain.	Adapt: Successfully adapts an appropriate exemplar to his/her own specifications.	Model: Successfully reproduces an appropriate exemplar.
<b>Taking Risks</b> <i>May include personal risk (fear of embarrassment or rejection) or risk of failure in successfully completing assignment, i.e. going beyond original parameters of assignment, introducing new materials and forms, tackling controversial topics, advocating unpopular ideas or solutions.</i>	Actively seeks out and follows through on untested and potentially risky directions or approaches to the assignment in the final product.	Incorporates new directions or approaches to the assignment in the final product.	Considers new directions or approaches without going beyond the guidelines of the assignment.	Stays strictly within the guidelines of the assignment.
<b>Solving Problems</b>	Not only develops a logical, consistent plan to solve problem, but recognizes consequences of solution and can articulate reason for choosing solution.	Having selected from among alternatives, develops a logical, consistent plan to solve the problem.	Considers and rejects less acceptable approaches to solving problem.	Only a single approach is considered and is used to solve the problem.
<b>Embracing Contradictions</b>	Integrates alternate, divergent, or contradictory perspectives or ideas fully.	Incorporates alternate, divergent, or contradictory perspectives or ideas in a exploratory way.	Includes (recognizes the value of) alternate, divergent, or contradictory perspectives or ideas in a small way.	Acknowledges (mentions in passing) alternate, divergent, or contradictory perspectives or ideas.
<b>Innovative Thinking</b> <i>Novelty or uniqueness (of idea, claim, question, form, etc.)</i>	Extends a novel or unique idea, question, format, or product to create new knowledge or knowledge that crosses boundaries.	Creates a novel or unique idea, question, format, or product.	Experiments with creating a novel or unique idea, question, format, or product.	Reformulates a collection of available ideas.
<b>Connecting, Synthesizing, Transforming</b>	Transforms ideas or solutions into entirely new forms.	Synthesizes ideas or solutions into a coherent whole.	Connects ideas or solutions in novel ways.	Recognizes existing connections among ideas or solutions.

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