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Critical and Creative thinking Activities for Engaged Learning in Graphics and Visualization Course

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Critical and Creative Thinking Activities for Engaged Learning in Graphics and Visualization Course

Introduction

In this paper we address the use of, and student response to, a set of ideation methods for conceptual design employed in a freshman-level engineering graphics course. The paper makes the following three contributions to the engineering education literature. First, we have coined the term UnTiED (**Un**conventional **T**hinking **i**n **E**ngineering **D**esign) ideation methods to describe a set of methods which can be used to help students' creative processes when developing engineering conceptual design solutions. Second, the paper provides student perceptions about the impact of using UnTiED ideation methods in addition to conventional and structured ideation methods in an engineering graphics course setting. Third, we explore how complex, time-intensive, research-based assessment instruments to measure creativity can be to grade students' creative work in a single instructor's course. These contributions emerged from two basic research questions:

(1) What are students' perceptions about the use of specific practices to foster ideation as a part of the conceptual design process?
(2) How can an instructor in an engineering course using ideation methods for design assess the creativity and quality of student work produced by these methods?

Next, we will describe how engineering graphics relates to the design process and present a literature review to describe prior work in several areas related to ideation for engineering conceptual design. Then, we describe the UnTiED ideation approach and our efforts to address the two research questions we have posed. Finally, we offer our thoughts about what the next steps to this research might be.

Literature Review

Engineering graphics and visualization:

Visualizing three-dimensional objects and manipulating them in one's mind is an essential part of the engineering design process through which engineers and designers generate new ideas and solve problems. Introduction to Engineering Graphics and

Visualization (or a course of a similar title) is a freshman engineering course in many universities. There is evidence that freshman cornerstone design courses enhance student interest in engineering while increasing retention in engineering programs[1]. The role of sketching in design is well- documented[2], as sketching is not simply an illustration of design cognition, but an important vehicle for the design thought process[3]. Sketching activities happen throughout the engineering design process to capture and communicate ideas generated during design[4, 5] and have been closely linked with design thinking and creativity.

Does good sketching ability influence design outcome?

Sketching ability can be assessed through sketching tasks that emphasize different aspects of drawing in the design process, including drawing facility (see and sketch with hand-eye coordination), mechanical recall (sketching similar products from memory), and novel visualization of new objects (sketching with formal training in using projection theories)[2]. While the use of sketching during the ideation stage of conceptual design is extensively studied in the literature, very limited literature exists on the influence of sketching ability on the quality of the final design product. While some preliminary results suggest that designers who are given sketching instruction tended to draw more overall, no conclusive correlations were found between the sketching skills and design outcome[2, 6]. There is some literature available on the positive relationship between the amount of three-dimensional 3D perspective sketching and design outcome[7]. With regards to orthographic projections and dimensioning aspects, it is observed that the quantity of dimensioned drawings created early in the design cycle is significantly linked with design outcome[8]. More research[9] is needed on development of a perspective-based sketching curriculum and how this compares to more traditional methods of teaching free-hand sketching to students in a freshman level engineering graphics course. Sketching ability, in terms of drawing something accurately or realistically, is a necessary but not necessarily sufficient skill for learning design thinking and influencing the design outcome.

Design thinking in engineering education and challenges:

Design thinking reflects the complex processes of inquiry and learning that designers perform in a systems context, making decisions as they proceed, often working collaboratively on teams in a social process, and "speaking" several languages with each other (and to themselves)[(10)]. In cornerstone design courses, design thinking skills that support an iterative loop of divergent (creative) and convergent (critical) thinking through individual and team project-based learning environments are needed in addition to instruction of graphics and visualization tools. Critical thinking skills have a more established history in academia and in engineering programs, most specifically for teaching problem solving. Universities teach creative thinking skills to a much lesser extent, perhaps because of a lack of understanding of how we define creativity[(11)]. There are several open research questions on design pedagogy and how effective inquiry, the systematic interplay between divergent and convergent questions, can be taught and promoted as part of engineering education. There are also unanswered questions about what defines creativity, how it can be measured, and how it relates to other characteristics of design thinking[(10)].

Conceptual design Ideation and known blocks:

Ideation is traditionally defined as a structured approach to thinking for the purpose of solving a design problem. Structured idea generation methods may be broadly classified into two categories: intuitive methods[(12)] and logical methods[(13, 14)]. There are also known barriers that work against the structured idea generation process[(15)]. *Design fixation* has been identified as a common problem; it is the tendency of a designer to favor a design from previous experience or a design seen or developed by the designer[(16)]. Another barrier that has been identified from the literature is *premature judgment* while developing designs and ideas[(17)]. This barrier may force designers to discard early design ideas that do not evaluate well. A *tight grip on problem specifications* and a tendency to *impose fictitious constraints* on the design[(15)] may cause potentially good designs to not be considered or eliminated prematurely when using structured ideation methods.

Unconventional Thinking in Engineering Design (UnTiED) ideation

Albert Einstein once said "You can't solve a problem with the same thinking that created it." The ideation process involves critical thinking supported with creative thinking. Although creativity may not be required for some products, creative solutions are usually required to break away from baseline product features and introduce features that delight customers[(18)]. In addition to using structured ideation methods, this research uses an inquiry-based approach to cultivate divergent thinking through UnTiED ideation in a cornerstone design course for freshman engineering students. The motivation for this work is derived from posing the following questions.

- Do our education and curriculum-based classroom teaching / learning cause us to think in a certain conventional way?
- Why is engineering design typically done with a set of predefined specifications (*tight grip on problem specifications*) operating within a restricted framework (*impose fictitious constraints*) with an end-use in mind?
- Does this way of thinking restrict our imagination and **tie** us down within the design space, leading to routine engineering products?
- How can we overcome the barriers of *design fixation* and *premature judgment* during the conceptual ideation stage of design?
- Should we ever design products without any predefined end-use in mind, reserving decisions about how the product can be useful until after the designing is done?
- How much fun will it be to question the status quo and design something just to quench one's curiosity thirst?
- How can one create engineering design ideas by seeking random connections with unusual combinations between unrelated concepts?
- Does absurdity (pattern breaking thinking) have any role in conceptual ideation? If so, how can we direct absurd ideas onto the right track in discovering new ideas?
- How about tinkering with many design ideas which are nonjudgmental and open ended?

- How can we come up with fun product ideas by challenging assumptions with reverse thinking?
- How do we **untie** ourselves from conventional thinking? What is the role of UnTiED ideation on creativity and student engagement in design courses?

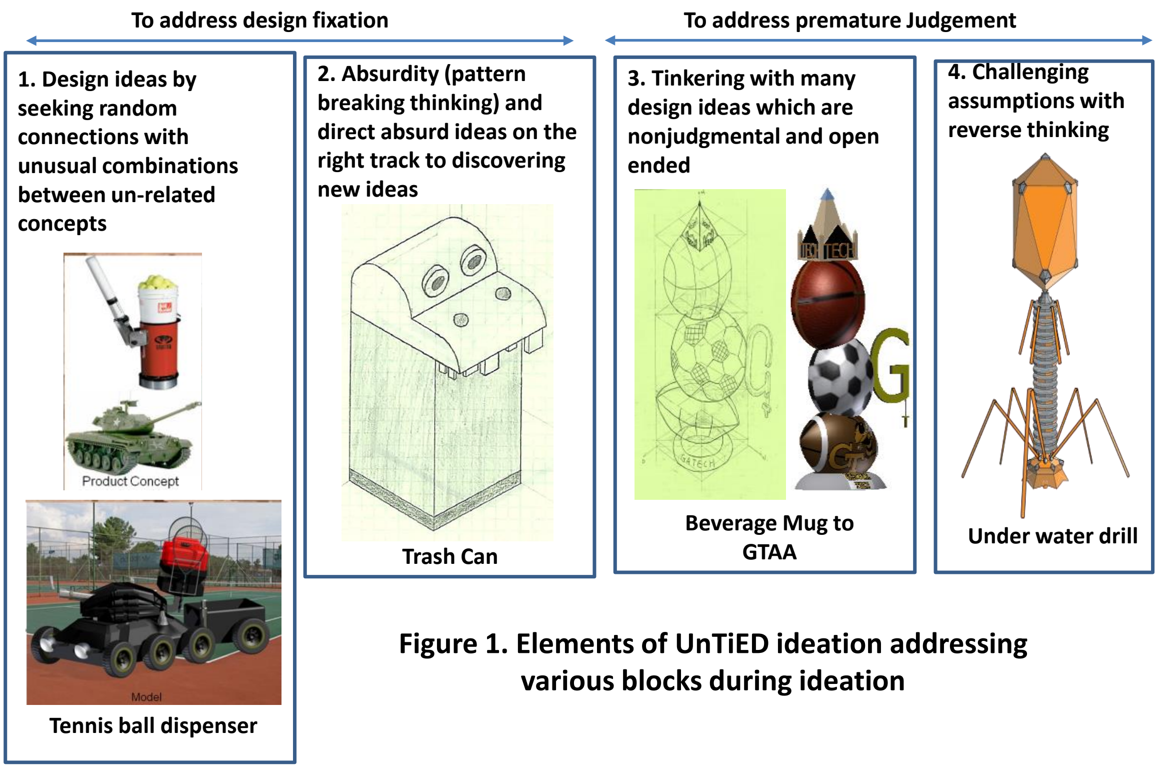

Figure 1. Elements of UnTiED ideation addressing various blocks during ideation

Figure 1 shows the four elements of UnTiED ideation, namely (i) random connections with unusual combinations between unrelated concepts, (ii) absurdity (pattern breaking thinking), (iii) tinkering with many nonjudgmental and open ended ideas, (iv) questioning the status quo and challenging assumptions with reverse thinking. Some examples of student work from the Fall 2015 semester under these four elements are also shown in Figure 1. Some of the underlying divergent thinking elements of UnTiED ideation shown in Figure 1 can be identified with similar strategies used in the literature in terms of using random connections[(17)], application of metaphors[(19, 20)], exploring variety of ideas with increased design space, use of analogies, and breaking rules[(21)]. The literature also presents some studies which attempts were made to quantify creativity in engineering courses[(18),(22)]. However, teaching divergent inquiry in design thinking is neither recognized clearly nor performed well in engineering curricula[(10)].

Role of ideation methods and research questions

Research Question #1: *What are students' perceptions about the use of specific practices to foster ideation as a part of the design process?*

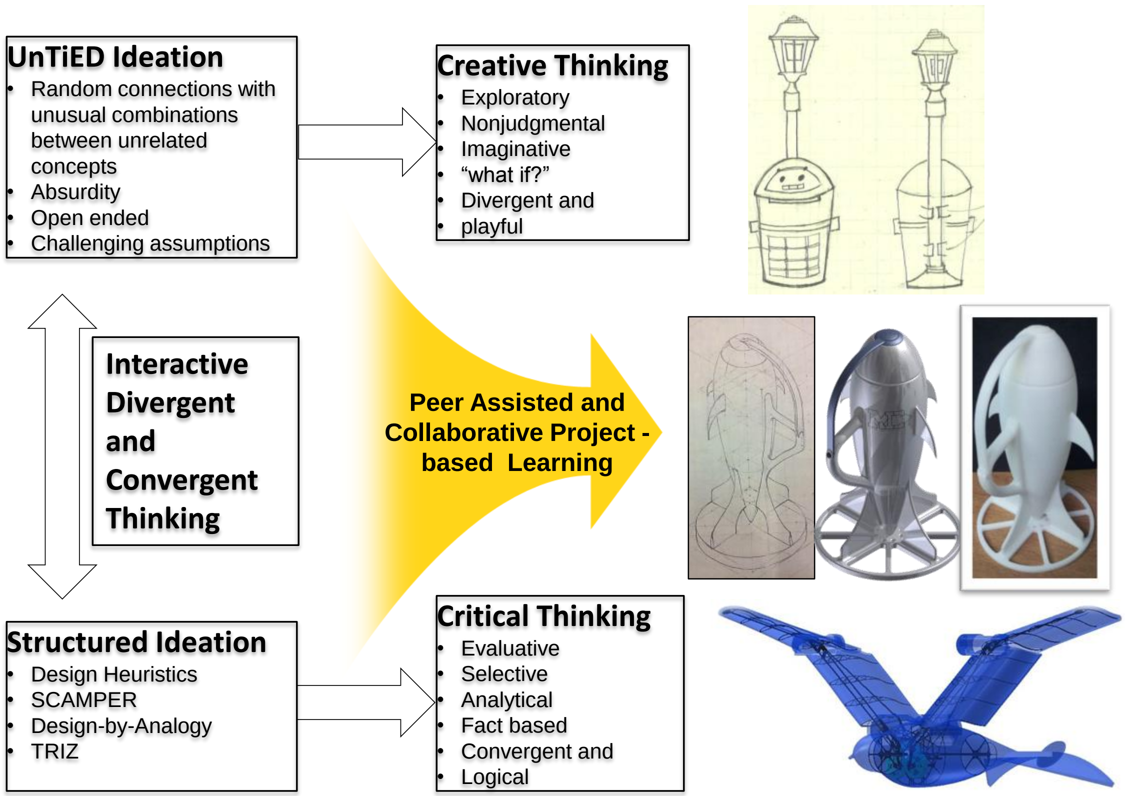

Figure 2. Critical and creative thinking activities with project-based learning (Spring and Fall 2015)

For students in engineering graphics and design education, emphasis on creativity during conceptual design can help in instilling excitement towards the subject. Various learning-centered instruction strategies[(23)] are implemented in a freshman engineering graphics course at Georgia Institute of Technology. With the instructor acting as a facilitator, the objective of each of these strategies is to increase student responsibility in learning through improved engagement. The course includes both individual and team projects under collaborative learning environments that teach sketching (general, pictorial and orthographic projections), 3D CAD, and 3D printing. Individual projects involve creative ideation, pictorial and orthographic sketching, 3D CAD, and 3D printing of consumer products. Team projects involve pictorial sketching of sub-assemblies and 3D CAD of large engineering structures and functional animations. The redundancy in the use of graphics and design tools in subsequent projects is intentional for performance improvements due to repetition[(24)] and to consolidate the concepts learned at various stages of the course. Figure 2 illustrates the critical and creative thinking activities with project-based learning. Though students use general sketching techniques for ideation, in this graphics course they are required to document their final designs using isometric or perspective pictorials and orthographic projections before using CAD to improve their visualization skills.

Students' perceptions on creativity aspects in the course

At the end of the course, a survey is employed which contains several open-ended questions. We searched the results for these questions from 322 respondents in 7 sections of the course from Spring 2015 and Fall 2015. There were a total of 18 comments related to "creativity", especially as related to student projects.

Here is the breakdown:

Of the 140 "Course: Best Aspect" comments, 17 (12.1%) mentioned creativity, or similar.

Of the 129 "Course Improvements" comments, none mentioned creativity.

Of the 32 "Other quality of the course" comments, none mentioned creativity.

Of the 39 "Other overall" comments, none mentioned creativity.

Of the 120 "Instructor's greatest strength" comments, 1 (0.01%) mentioned creativity.

Of the 105 "Instructor improvement" comments, none mentioned creativity.

Of the 36 "Instructor other" comments, none mentioned creativity.

The specific comments are included in Table 1 and fall into the following categories:

Table 1

Question: Course best aspect
Interesting and allowed for creativity

Learning to effectively use CAD was very helpful and I think it will help me a lot in my future careers. It was nice to be allowed to be creative with choosing what we wanted to model and make it our own.
The individual project was a great way to learn
working on your own designs for the Tests
Its a fun creative course
The creativity and freedom with design options
individual projects
The assignments given were open ended and allowed the students to be creative. This allowed for greater understanding of key concepts and enthusiasm in the course.
The best aspect for me was that the individual project and the group project gave me a creative outlet.
Open ended CAD projects
The best aspect of this course was the freedom we had to design creative things and to manage our own time.
I think the best aspect of this course was the ability to create and design. It combined practical aspects of logic and geometry with creativity.
The best aspect was being able to design our very own product from scratch in the many phases of design. Since these were take home exams they were much better focused towards learning and experimentation with the software rather than in-class assessments. They were also very enjoyable as I relished the challenge of creating my own product.
The personal design project was good for me because of the creative aspect and the way it was divided into three parts.
The group project and individual project were extremely open ended and allowed groups to demonstrate the skills learned in the course.

Seeing my own design develop from sketch to 3D object. Solidworks was (mostly) fun to use and creativity in the course was encouraged.
Learning the idea to creation process
Question: Instructor greatest strength
He always encouraged his students to think out of the box when solving a problem or creating a design.

The 18 comments (Table 1) were analyzed using an open-coding approach by a researcher not involved with teaching the course. Each clause relating to some aspect of creativity in the course projects was first given a summary code. Then, a second pass on the codes was made to revise and combine codes into themes in light of the first attempt at coding. Some clauses received more than one code due to combined ideas present in the text.

In all, 39 individual components of the comments were coded. The coding resulted in the following themes, ordered from most to least prevalent:

- Being "allowed" to be creative within the course (9)
- Student feeling a sense of "ownership" of their work or learning (9)
- The "open-ended" nature of the creative process (7)
- Course assignments incorporating creativity generates a "fun/engaging" learning atmosphere (5)
- Creative design is an effective "way to learn" (5)
- Multiple "stages" in the creative design process was helpful

It is notable that the word "allowed", and several similar words or phrases, came about as a major theme. The idea that students in engineering programs should be learning to generate creative design solutions is quite ubiquitous, yet students appear to find it a notable rarity. It would also seem natural that a creative process should be "open-ended," thus naturally fostering feelings of personal "ownership" of learning among students, as displayed in the comments students made.

Survey, Fall 2015: Results for Ideation Method Items

In Spring and Fall 2015, the course instructor introduced several structured ideation methods (both intuitive[12] and logical[14]) to all students through available literature and videos. In all design projects, students were encouraged to start the ideation process with UnTiED ideation elements and were required to choose one structured ideation method from the provided list. A survey was then conducted at the end of Fall 2015 semester.

Methodology

Data Source

End of Course Survey: The end of course survey consists of 42 to 55 items. It was administered to students in all sections near the end of the Fall, 2015 semester. The survey covered various components of the course. A subset of these survey items (13 items) focused on assessing student patterns of use and perceptions of the various ideation methods introduced by the instructor. These ideation method survey items included a) a checklist grid in which students were asked to indicate whether they used each ideation method on each of three course projects, b) Likert-type items on perceptions of the ideation methods, and c) open-ended items on the ideation methods.

Data Collection:

Online web survey software, SurveyMonkey, was used to administer the survey. The web survey has built-in advantages such as question ordering and clear guidance/instructions throughout for the participants. Web surveys allowed us to collect the data in a relatively short amount of time. The whole survey took approximately 15 minutes to complete, and the subset of ideation methods items took less than 5 minutes to complete.

41 students completed the survey. Invitations to participate were sent to 139 students for a response rate of 29.5%. One possible explanation for the low response rate is that e-mail invitations were sent out during a time when several course deadlines occurred and students were preparing for final exams. One student’s responses were deleted because the student completed the demographic items but none of the survey items.

Results:

The following table shows the demographics of students who responded to the end of course survey. The respondents were predominantly men (70.73%).

Table 2: Survey Respondents by Gender

Gender	*Count*	*Percent*
Male	*29*	*70.73*
Female	*12*	*29.27*

Further, students who responded to the survey were mostly mechanical engineering (ME) majors (73.17%) with a smaller representation of aerospace engineering (AE) majors (19.51%).

Table 3: Survey Respondents by Major

Major	*Count*	*Percent*
AE	*8*	*19.51*
ME	*30*	*73.17*
Other	*1*	*2.44*
Missing	*2*	*4.88*

Patterns of Student Use of Ideation Methods

Student reports of the ideation methods they used varied by project. For Project 1, Design Heuristics was used by the largest portion of students (58.54%), followed by SCAMPER (48.78% of students) and Design-by-analogy (39.02% of students). For this project, nearly a third of student also reported using the remaining two ideation methods, Lateral Thinking (29.27%) and TRIZ (29.27%). So for this project, some ideation methods are more popular than others, but each method was used by at least roughly one third of students (see Table 4).

For Project 2, Design Heuristics was again associated with the highest level of use, with over two thirds of students reporting that they used it (65.85%). Over half of students used Design-by-analogy (51.22%), and nearly one third of students used SCAMPER (29.27%). Lower usage of Lateral Thinking (17.07%) and TRIZ (2.44%) was reported by students on Project 2 (see Table 4).

For Project 3, the most popular ideation method was Design-by-analogy (48.78%), followed by Lateral Thinking (34.15%) and Design Heuristics (36.59%). Nearly one third of students used SCAMPER for Project 3 (29.27%), with a much smaller group using TRIZ (12.20%) (see Table 4).

Table 4: Patterns of Student Use of Ideation Methods

Ideation Method	***Project 1 (Trash Can/Solar cooker)***	***Project 2 (Beverage Mug/Perfume Bottle/Water Bottle/Soap Dispenser)***	***Project 3 (Team Project)***
	% Used	***% Used***	***% Used***
Design-by-analogy	*39.02*	*51.22*	*48.78*
Lateral Thinking	*29.27*	*17.07*	*34.15*
SCAMPER	*48.78*	*29.27*	*29.27*
TRIZ	*29.27*	*2.44*	*12.20*
Design Heuristics	*58.54*	*65.85*	*36.59*

Student perceptions of ideation methods:

Students were asked a series of questions about their perceptions of the ideation methods and the extent to which they benefited in specific ways as a result of using the ideation methods. These items indicate that student perceptions of the ideation methods were generally positive. On a response scale from 1 (strongly disagree) to 6 (strongly agree), mean responses were above the 3.5 midpoint, the cutoff between negative and positive responses. No mean responses exceeded 4.5, indicating that, on average; student perceptions of the ideation methods fell into the neutral to agree range.

As can be seen from Table 4, students preferred to use the design heuristics[(25)] ideation method for project 1 (58.54%) and project 2 (65.85%), while for Project 3, design-by-geometric-analogy (48.78%) was chosen most frequently, followed by design heuristics[(25)] (36.59%).

Table 5: Student Perceptions of Ideation Methods

Item	***N***	***Mean***	***SD***
The ideation methods were useful	*40*	*4.20*	*1.16*
The ideation methods enhanced my ability to think creatively	*40*	*4.18*	*1.17*
The ideation methods enhanced my ability to think critically	*40*	*4.13*	*1.28*
I will use the ideation methods in later classes, even when they are not directly assigned	*40*	*4.05*	*1.26*
The ideation methods improved my overall performance on the design assignments in this course	*40*	*3.98*	*1.37*
The ideation methods were enjoyable	*40*	*3.93*	*1.35*

Response Scale: 1 = Strongly Disagree to 6 = Strongly Agree

With respect to the specific items, students expressed a moderate level of agreement that the ideation methods were useful (mean = 4.20) and enjoyable (mean = 3.93). They agreed that the ideation methods enhanced their ability to think creatively (mean = 4.18) and critically (mean = 4.13), and also that the ideation methods improved their performance on design assignments (mean = 3.98). Lastly, they expressed a moderate level of agreement that they would use the ideation methods in later classes (mean = 4.05) (see Table 5)

Open-ended feedback on ideation methods

Students were asked two open-ended questions about the ideation methods. The first of these was "Please describe how the ideation methods you used affected the level of creativity you achieved with your design activities throughout the semester." Only 24 of the 40 students provided responses to this question; their responses encompassed a range of opinions on the ideation methods from positive to negative. Most positive comments related to the ideation methods promoting creativity and idea generation, while the negative comments often related to students finding the ideation methods unhelpful and feeling that they could be creative without needing the ideation methods. Example quotes from student responses are provided below.

Quotes from student responses:

"They gave me ways to think about a design that I would not have otherwise thought about."

"They motivated me to think of things differently and come up with creative solutions."

"The ideation methods allowed me to think outside the box which in turn helped me make creative designs"

"Honestly they didn't really help my creativity. I felt like they were forcing me to think a certain way to be creative, instead of just letting something come to me."

"I feel I am a creative individual and am able to think creatively without having to follow guidelines to think creatively"

"I actually felt that most of the time, the ideation methods forced us, engineers, to think less technically and assume the role of a designer. This in and of itself isn't bad, but it's not my forte or job as an engineer. More often than not, I felt that all of the rules and precepts associated with the ideation methods were limiting and stressful."

The second open-ended item focused on comparing various ideation methods and asked students to describe which was used more commonly then others. Only twenty-two students provided responses to this question. Students did not specify the reasons why they chose certain designs over other. They also did not explicitly discuss their elimination reasons for each design. Design by analogy, design by heuristics and scamper were most mentioned. The lateral thinking and Triz were the least mentioned. Below are some examples of their perceptions about using each method.

"I find Design Heuristics the most productive because it clearly says what one way to change the idea"

"The only ideation methods I used were scamper and design by analogy. I found others to be less helpful."

"There were ones I felt more comfortable with; in addition I feel some projects require an ideation method such as design heuristics while other might need other type like lateral thinking. I determined which one to use based on the goal I wanted to achieve."

"Scamper was the technique we generally used because it was simple and easy to understand. It also allowed us to think "outside the box" in terms of application. Design Heuristics was difficult to use because we did not have access to the cards themselves."

Research Question #2: *How can an instructor in an engineering course using ideation methods for design assess the quality of student work produced by these methods?*

For many years, Psychologists and the design community have studied creativity. Their experiments have different central themes for validity. Creativity Assessment tools can be broadly classified based on (1) experiments done by psychologists[(26)], (2) design experiments done by engineers[(27)] (3) tools based on work from psychologists and members of the design engineering community[(28-30)], and (4) holistic assessment tools to quantify domain specific creativity[(31)]. However, assessment tools with combined effort from creativity researchers and engineering educators is sparse[(18)]. How can an instructor best assess student design projects in terms of creativity?

There is evidence that the cognitive operations that are required for creativity can be taught. In addition to repeatedly reminding students how to be creative, there are other challenges for educators [(32, 33)] who want to promote creativity in the classroom; these challenges include:

1. Lack of knowledge of instructional strategies to help students be more creative.
2. Difficulty in using quantitatively-oriented creativity assessment tools available in literature.
3. Lack of assessment rubrics that are
    a. customizable
    b. subject-domain specific
    c. inclusive of subjective and objective measures of design aspects and course objectives and
    d. easy to implement.
4. Lack of knowledge on the effect of the open-ended nature of creativity activities in the curriculum and its impact on students' mindset and learning.

The primary objective of this research is to assess students' engagement and quality of work in their projects due to synergetic influence of following aspects:

- Combining the proposed UnTiED ideation approach for creative thinking with structured ideation methods for critical thinking during conceptual design

- Teaching general, pictorial sketching techniques and orthographic projections during the ideation stage, and
- Use of both peer-assisted and collaborative design activities in a project-based learning environment

Exploring existing creativity assessments and evaluating the need for new creativity assessment rubrics for engineering education is another key aspect of this research. To this end, an existing creativity assessment, Creative Engineering Design Assessment (CEDA)[(28)], was considered for use in this research as a way to explore possible creativity differences between the experimental and control groups. A pilot effort with CEDA was undertaken during the Fall 2015 semester in order for the investigators to gain familiarity with the instrument's administration and scoring requirements, and also to ascertain its suitability for our research. Nine students took the CEDA, and the authors met as a group to practice scoring the instrument and to determine whether the skills evaluated by the instrument matched our outcome of interest. While the authors found the instrument useful and felt consensus on the scoring could ultimately be reached, it was determined that CEDA assesses creativity in engineering design in a more global sense than would be ideal for this project.

While fostering creativity in design is frequently cited as a goal in design curriculum development and in the development of maker spaces and fabrication facilities[(34)], it is difficult to measure and quantify creativity in engineering design courses. Particularly in the design education community, many attempts have been made at defining creativity in specific contexts that consist of a set of quantifiable attributes in student design products[(18)]. In a paper by Oman et al,[(18)] a summary of some of the available creativity metrics including Comparative Creativity Assessment (CCA) and the Multi-Point Creativity Assessment (MPCA) are presented and compared with each other and general ratings by judges. In the CCA, creativity is effectively a function of novelty and quality for a number of ideas generated to achieve a particular function. The functions are broken down in such a way that the score is based primarily on item counts per function, which does not require 'judging.' The MPCA allows raters to assess creativity for a set of criteria which are assigned weights. However, given the associated complexities with applying either metric as compared to simply 'judging' creativity of design artifacts on a scale from 1-10, the three methods do not exhibit a high level of agreement and the interrater reliability is higher for the score out of 10 than for the MPCA. The problem is that either creativity needs to be broken down into countable or measurable attributes, like the CCA, or is subject to human perception, like judging or the MPCA. However, the most creative design as determined by all three metrics is the same design in this particular study.

There are also some holistic assessment tools available to assess domain-specific creativity. For example: The Test for Creative Thinking - Drawing Production (TCT-DP)[(31)] was designed to mirror a more holistic concept of creativity than the quantitatively-oriented, traditional divergent thinking tests. The test has been normed with various age and ability groups. The TCT-DP, in addition to other constructs, also includes unconventionality in the produced drawings in terms of (i) manipulation of the material; (ii) fictional and/or abstract elements or drawings; (iii) any usage of symbols or signs and unconventional use of given fragments.

Proposed Creativity Rubric:

There are many definitions of creativity in the literature. For the purpose of this research following definition [(35)] is used. "Creativity is the interaction among aptitude, process, and environment by which an individual or group produces a perceptible product that is both novel and useful as defined within a social context". The creativity evaluation methods [(36)] include (i) Divergent thinking tests (ii) Peer / teacher assessment (iii) self-assessment and (iv) Consensual assessment : a product-based assessment of domain specific and domain general knowledge by expert judges

Divergent thinking involves cognitive processes that help to produce multiple solutions for open-ended problem. The foundation for divergent thinking is ideational fluency. On the other hand Novelty/originality defines the uniqueness of the idea. Does fluency have large influence on originality scores? Does the best way to get a good idea is to get a lot of ideas? Literature [(36)] suggests that the effect of fluency and originality should be carefully considered in scoring. For example, considering a summative or weighted fluency scoring system can influence the inter-rater reliability and predictive validity of a scoring system.

Table 6: Rubric for choosing creative designs in student projects

Creativity Based Subjective Measures					Skill Based Objective Measures			
Student Last Name	**Fluency (0-8)**	**Originality (0-4)**	**Elegance (0-4)**	**Relevance (0-4)**	**Design Visualization (0-10)**	**Design Complexity (0-10)**	**Design Documentation (0-10)**	**Total Points**

Both creativity based subjective measures and skill based objective measures are used
Skill based objective measures align with course objectives and learning outcomes
Combination of domain-general and domain-specific traits

From domain-general to domain-specific rubric items

Fluency

Design Variations	Points
1	0
2 to 4	4
5 or more	8

Originality

Rubric	Points
Common	0
Interesting	2
Unconventional (or)	4
Innovative	4

Elegance

Rubric	Points
Common	0
Pleasing	2
Graceful	4

Relevance

Rubric	Points
Not Relevant	0
Moderately	2
Very relevant	4

Design Visualization	Points
Perspective Fundamentals	0-5
Sketching Techniques	0-5

Design Complexity	Points
Part Complexity	0-5
Assembly Complexity	0-5

Design Documentaion	Points
Drawings and Dimensioning	0-5
Design Description	0-5

1.Fluency: Number of unique designs (sketches) provided
2. Originality (from mundane to unconventional to innovative)
3. Elegance (Pleasing to Look beyond functionality and Purpose)
4. Relevance and Effectiveness (Related to functionality and purpose of design)
5. Design Visualization (DV): quality of sketching (0-10), perspective fundamentals
6. Design Complexity(DC) : Challenging part modeling and assembly (0-10), good use of modeling and assembly CAD
7. Design Documentation(DD): Part and assembly drawings, dimensions, design description and report (0-10)

Table 7: Rubric items and measures

Rubric	Measure of
Ideational Fluency and Originality	Divergent thinking (Domain-general and subjective)
Elegance	Aesthetic value (Domain-general and Consensual)
Relevance	Design insight (Domain-specific and subjective / objective)
Design Visualization	Spatial visualization and sketching abilities (Domain-specific and objective)
Design Complexity	CAD skills (Domain-specific and objective)
Design Documentation	Design intent (Domain-specific and objective)

While divergent thinking is one major aspect of creativity assessment, there are teacher rating approaches [(37)] in evaluating the creative aspects of students' creative products such as originality, technical goodness, and aesthetic appeal factors. Componential model of creativity [(38, 39)] predicts that three major components contribute to creativity: domain-specific skills, general creativity-relevant skills (cross-domain) and task motivation. A rubric (see Table 6) that combines both domain-specific and creativity-relevant skills is proposed in this work and currently being used to select best student designs in student projects. Table 7 describes the rubric items with subjective and objective measures of various domain-specific and domain-general aspects. More research is needed to predict the inter-rater reliability and validity of the proposed rubric.

Next steps and thoughts

We plan to expand this research in the coming semesters by implementing an experimental vs. control group design in which some of the course instructors' sections will be taught UnTiED ideation method described in this paper in combination with the design heuristics ideation method, the preferred method from the 2015 data, (experimental group) while the other sections will be introduced brainstorming only (control group). While the UnTiED ideation elements can aid creative thinking in the conceptual domain, design heuristics cards can facilitate critical thinking within the knowledge domain and product constraints. Combining these two methods can provide an interactive divergent-convergent thinking process during conceptual design, as illustrated in Figure 2.

The control and experimental groups will be compared on creativity. Creativity will be assessed with previously-used idea generation design problems such as "Peanut Sheller,"[40] as well as a newly developed creativity rubric for individual student projects. This comparison will allow us to investigate the effects of the ideation methods on creativity in engineering design. Student perceptions on the ideation methods will also be collected with a survey similar to the one used in Fall 2015. Because our intervention primarily consists of ideation methods intended to impact students' creativity in generating ideas within the context of design problems, an assessment more directly focused on the idea generation phase of the design process would be more suitable for our research. We plan to use a set of idea generation problems which have been used successfully in the past to measure outcomes related to creativity in idea generation.

In future work, student ideation artifacts and projects will also be examined through the lens of the MPCA[18]. Even though the metric requires raters and does not exhibit high reliability, the fact that the metric is broken down by function may allow us to better trace the source(s) of a high or low creativity score than could be determined from a single, simple rating.

A variety of research tools are available to measure different aspects of creativity as a part of the engineering design process. However, these tools can be highly complex and time-intensive to implement for a single instructor simply trying to foster, and measure, creativity in their classroom. Often, instructors resort to a holistic rubric with a basic description of expectations as the mechanism to assign grades. Or, they create a simple analytic rubric with 2 or 3 criteria based on their intuition and course objectives. However, a tool bridging the two extremes of complex research protocols and simple homegrown rubrics is missing. Creating classroom design activities that are focused on specific design skills and developing assessment tools with objective and subjective measures and skill-based rubrics[41] are needed to determine the strengths and weaknesses involved in teaching design learning to students. With the creativity rubric proposed in this work, we seek to document the beginning of a case study to improve the tool for general academic use in engineering education, in particular for a freshman-level engineering graphics course that incorporates several design projects. Creativity assessment tools based on complimentary research efforts from creativity researchers and engineering educators can accelerate the process of incorporating creativity into the engineering curriculum.

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