ABSTRACT

This work describes an experiment to research improving the ideation performance of undergraduate engineering students in classroom settings. This research investigates the impact of TRIZ, increasing emphasis on sketching during design, and using the Pulse Smartpen, on ideation performance. The research team's goal is to develop an experimental design and protocols for this suite of ideation tools. Successful experimentation will provide a standard way to benchmark ideation tool effectiveness. The experimental design includes training students in the appropriate tools for their treatment condition and presenting students with an ideation design assignment. The design assignment results will be analyzed using ideation measures of novelty, variety, quantity, and quality as defined in the literature. Results from pilot work at three institutions are introduced here along with observations on the experimental process to date.

1 INTRODUCTION

Industrial and academic leaders are concerned about creative potential of future engineers. Lack of creativity is viewed as problematic in a rapidly changing technology-oriented world where generating new ideas is essential to survival [1,2]. Industrial employers perceive that new BS engineering graduates lack design capability, creativity, and the practice of considering alternatives during the design process. Universities have responded to these challenges by adding more design content and introducing more open-ended design problems into their engineering curricula. Nevertheless, the burden of improving student creativity in design falls to the course instructor.

Literature review and experience lead the authors to view the design ability of engineering students as built upon a foundation in three areas: 1) design process knowledge; 2) design analysis knowledge; and 3) creative processing ability, also called ideation. Generally, design process knowledge is taught in the first year or introductory design courses and then practiced throughout the engineering curriculum culminating in the capstone design course. During second and third years, the curriculum focuses on analytical concepts and design analysis techniques. It is rare to find an undergraduate course in an engineering curriculum focused on improving student's ideation skills.

Engineering design course instructors face a nearly insurmountable task: devise a combination of instructional events that will allow students to learn the best design methods possible and give them tasks that they can use to demonstrate their learned capability. Meeting this mark is not enough anymore. Now instructors must lead students to learn to be creative in their designs and innovative in their applications so that they can become the next generation of successful technology entrepreneurs. Currently, this is an impossible standard to meet. However, effective research on design learning will allow design theory and methodology researchers to make recommendation to improve design education practice. This research focuses on the impact of using creativity enhancing methods and tools to improve engineering students' design ideation process. These tools can be used within existing courses and won't require curriculum disruption.
We propose to rigorously test three tools in design classes to determine if the tools improve ideation performance on a test problem. The first tool is a design problem solving approach named TRIZ (an abbreviation of a Russian acronym of “Teoriya Resheniya Izobretatelskikh Zadach” meaning theory of inventive problem solving). TRIZ is a design method mostly taught in graduate courses and professed as effective by a significantly sized user community. In this investigation, TRIZ will provide the systematic innovative problem solving method, an emphasis on sketching will externalize concepts perhaps enhancing the design ideation, and Pulse Smartpen will capture the ideation outcomes seamlessly, and might decrease the cognitive load.

This paper presents the proposed research framework, the initial experimental setup, the results of a pilot study and the lessons learned for future experiments. The work is undertaken by four faculty members with complementary expertise and students from four institutions with diverse populations: Penn State University, University of Texas-El Paso, Texas A&M University, and the University of Maryland.

2 BACKGROUND
Traditional approaches to creativity (e.g., brainstorming) call upon designers to look inward for inspiration, and then communicate their ideas to others to create a synergetic and shared experience. This work focuses on methods and practices that provide additional external information and motivation to enhance the ideation process.

2.1 TRIZ as a Creative Design Method
TRIZ is a systematic approach to the generation of innovative designs to seemingly intractable problems. It was first developed in Russia by Genrich Altshuller after World War II and grew in prominence there in the early sixties and seventies. TRIZ has been used for many years in Europe and Asia and the method’s popularity continues to grow. TRIZ is based on the analysis of hundreds of thousands of patents. These original analyses articulated numerous solution patterns from diverse disciplines. The patterns and the tools are continually being updated by researchers worldwide. TRIZ has been recognized as a concept generation process that can develop clever solutions to problems by using the condensed knowledge of thousands of past inventors. It provides steps that allow design teams to avoid the “psychological inertia” that tends to draw them to common, comfortable solutions when better, non-traditional ones may exist.

Success stories of TRIZ involving established companies exist (e.g., see [3] for comprehensive studies of TRIZ usage at Ford and Hewlett Packard). In a relevant study done by Okudan et al. [4], the ideation effectiveness of TRIZ and brainstorming used together was compared to using brainstorming alone. Outcomes were measured by three ideation metrics: quantity, variety, and novelty as described by Shah et al. [5]. The design problem students solved was focused on air velocity control for fumehoods, and was presented by an industry sponsor. Results indicate significant gains in ideation metrics when TRIZ is used with brainstorming.

Research testing the impact of providing starting ideas during the process of ideation is relevant to the use of TRIZ. Researchers in the UK found that introducing stimuli in the form of TRIZ innovative principles supported the rate of idea generation during brainstorming sessions and lead to less obvious ideas [6]. Work with student groups concluded that the nature of the provided stimulus was important on its ideation impact. This study found that the more disparate the stimulus is, the more difficult it seems to be for designers to use it, thus the context within which the cues are provided is important for success [7]. Another study with engineering students focused on the impact of lexical stimuli (words) on design generation and found that students tended to use the words as verbs, especially when the stimulus was seemingly unconnected to the design task [8]. The same lexical study found that the dichotomous stimulus (like that presented in the TRIZ method) led to concepts that were judged by raters to be more novel than other concepts.

2.2 Hand Sketching as a Creativity Enhancer
Sketching was a critical skill in traditional engineering design but the practice has become less important to students as computer-aided drawing tools have become available.

The act of sketching is a both physical and mental process. A well used description of sketching is that a sketch is a designer’s ‘conversation with themselves’. What happens physically during sketching is easy to see and understand. The cognitive processes involved in sketching have been explored by many researchers in various concentration areas, including: engineering, architecture, art, education, and psychology. Much work has been done using protocol studies and the reader is referred to analysis of work on that topic by Purcell and Gero [9].

Sketching is not only the engineers’ way to work [10] but is recognized as a tool for ideation. Larkin and Simon [11] have shown that sketches are useful in problem solving because of their conciseness of representing data compared to sentential descriptions, in part because of its spatial relationships and also because sketching allows fleeting thoughts in the mind to be captured quickly [12]. Sketches also act as gestalts allowing designers to read off from the sketch far more information that was invested initially creating the sketch. Shah et al. [13] found that the use of sketches promotes novelty and variety, two measures related to divergent thinking. McCormick [14] also asserts that “Sketching is the tool for innovation, and is so vital to the engineering process that it should be taught and used as an essential part of engineering education and professional practice.” However, there is also limited evidence on the contrary. For example, Bilda et al. [15] conducted a think-aloud experiment with experienced architects (N=5) and reported no significant difference between sketching and not sketching during conceptual designing. Given the contradicting evidence more experimentation is necessary.
3 RESEARCH METHODOLOGY

This research work involves rigorous experimental designs to collect quantitative and qualitative data to answer the following three research questions to formulate an effective curriculum for integration to design focused courses.

**Research Question 1:** Can TRIZ improve the ideation performance of engineering students? It is hypothesized that the training of students in the TRIZ ideation method will improve students’ ability to generate innovative concepts.

**Research Question 2:** Can emphasizing sketching improve the ideation performance of engineering students? It is hypothesized that the emphasis on sketching will stimulate the creativity of students in design ideation.

**Research Question 3:** Can technology enabled journaling improve the ideation performance of engineering students? It is hypothesized that the novelty of using the Pulse Smartpen as well as reduction in the cognitive load will engage students in the sketching process. The Pulse Smartpen has simultaneous digital image and audio capture capabilities ([http://www.livescribe.com/smartpen/index.html](http://www.livescribe.com/smartpen/index.html)). The Smartpen is a well-fitting data collection instrument in the guise of a designer’s pen that can minimize the bias introduced to data. The Smartpen acts as a technologically sophisticated device that may act to improve student motivation.

### 3.1 Experimental Design

The experimental process is summarized in a diagram in Figure 1 and descriptions of the experimental interventions for each study factor (i.e., independent variable) are summarized in Table 1. Based on the hypothesis, the design of experiments is defined with the appropriate factors (i.e., independent variables), levels (i.e., treatments or interventions), responses (i.e., metrics), and replications (the experimentation is distributed among the participating universities to gather a breadth of data). The experiments will be run in a full-factorial fashion (total of $2^3 = 8$ runs) to investigate the main effects as well as the interaction effects among factors.

The experimental design requires that student participants prepare a set of design solutions in response to a predetermined design task (called the Ideation Assignment). Student participants are grouped into various treatment conditions to fit the experimental design. The faculty researchers at the study locations administer the treatment interventions which are sets of training or the use of Pulse Smartpens for the Ideation Assignment.

#### Table 1. Proposed Experimental Interventions

| Treatment Application | TRIZ Training: Two 50-minute TRIZ lectures will be given  
• Training materials on TRIZ and the specialized inventive principles and cataloged examples (developed by Kremer under the CCLI Grant DUE 0445944)  
• The same set of study materials and examples will be available to students in an online module through course management software. |
| Sketching Emphasis: The Ideation Assignment will require submission of sketches from each individual student. This intervention was piloted by Grenier [16] and consists of one, 50-minute learning module. The material includes a companion reading assignment and instructions for leading a class discussion. |
| Smartpen for Journaling: Each student will receive the Pulse Smartpen and accessories to use over the period of data collection, which is the time required for the Ideation Assignment. |

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It is important to note that the Sketching Emphasis treatment condition does not consist of an intervention to alter the sketching skills of students. The intervention is a learning module intended to encourage students to use their existing skills. Providing an intervention to teach sketching skills is outside the realm of the study. It is also a goal of the study to see if students can be influenced at whatever level of sketching skills they possess. Grenier's findings indicate that the learning module on sketching importance influences students.

3.2 Assessing Ideation of Assignment Solutions

The ideas falling in the corresponding level for each function will be based on the effects' results to accept or reject the initial hypothesis.

Novelty is a measure of how unusual an idea is as compared to other ideas. There are two approaches to measuring novelty: a priori and a posteriori. Novelty a priori requires the definition of what designs are expected before actually analyzing the ideas. The ideas generated can be analyzed based on the functions (f) the solutions must fulfill. The evaluator predefines each function at different levels (e.g., high, medium and low) based on the type of the ideas expected. The ideas falling in the corresponding level for each function receives a novelty score (e.g., High-10, Medium-5, Low-1). An a priori novelty score can be calculated for each concept by assigning weights for each function and aggregating them.

The higher the occurrence of a particular solution, the lower the novelty score. A novelty score for the entire design can be calculated using the formula:

\[
Novelty \text{ (a posteriori) Score} = \sum_{j=1}^{m} f \sum_{k=1}^{n} S_{jk} P_k
\]

\[
S_{jk} = \frac{T_{jk} - C_{jk}}{T_{jk}} \times 10
\]

Where:
- \( P_k \) = weight for the given function "k"
- \( T \) = total number of ideas for the given function
- \( C \) = number of occurrences of a particular solution for the given function

The higher the occurrence of a particular solution, the lower the novelty score. A novelty score for the entire design can be calculated by assigning a weight for each function and multiplying the separate novelty scores to obtain an overall novelty score. The expression for \( S \) is multiplied by 10 in order to normalize it (i.e., 0 is lowest while 10 is highest).

Variety measures the uniqueness of a set of concepts produced as solutions to the same design problem. When calculating the variety index, concepts are rearranged into a hierarchy structure defined by function. Within a function category, all the concepts are further differentiated by their working principles. The number of working principles in a function category greatly affects the value of the relative variety index. Similar to the novelty index, the higher the value of the variety index, the better it is. A set of ideas is analyzed by each of its functions to generate a "genealogy tree". The function to be fulfilled is the top of the tree then at the next level, the physical principles (or physical effects) that can be used to satisfy the function are given. For each physical principal one or more working principles are identified, and for each working principle one or more embodiments can exist. The tree is used to calculate a variety score for the set of ideas.

More branches at higher levels of the tree means a higher variety score, while more branches at lower levels of the tree means lower variety score. Figure 2 depicts generated ideas separated into two genealogy trees (one for each function).

![Genealogy Trees for "Produce Heat" and "Minimize Emission"](image)

The following formula calculates a score for variety:

\[
\text{Variety Score (function)} = 10x \sum_{k=1}^{l} \frac{S_k b_k}{n}
\]

Where:
- \( l = \) number of levels of abstraction used to describe ideas (i.e. physical principle, working principle, embodiment)
- \( S_k = \) rating score for level "k"
- \( b_k = \) number of branches at level "k" where each branch represents a different component type
- \( n = \) number of total ideas generated in the set

Shah et al. [3] suggest using 10, 6, 3 and 1 as weighting factors \((S_k)\) for a four level genealogy structure from top down. However, Nelson et al. [17] considered setting \( S_k \) to be 10, 5, 2 and 1 to provide a more differentiable result. The formula for variety is multiplied by 10 for normalization purposes. The overall variety score is calculated by assigning weights for each function and multiplying the variety score to obtain an overall score for the set of ideas (i.e., each idea in the set has the same variety score).

\[
\text{Variety Score (design)} = 10x \sum_{j=1}^{m} f_j \sum_{k=1}^{l} \frac{S_k b_k}{n}
\]

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Quantity is the total number of ideas generated in a specified amount of time. The premise of this measure is that generating more ideas increases the chance of better ideas. This score is directly assigned by counting the number of ideas each subject records during an experiment.

Quality is the measure of the feasibility of an idea and how close it comes to meeting the design specifications. The quality of an idea is an independent measure since it can be based on a physical property or ratio related to the performance of the artifact (e.g., time, weight, energy). At the conceptual stage, quality can usually be adequately estimated even though there is not enough quantitative information to do a formal analysis. At the embodiment stage, it may be possible to do some quantitative analysis perhaps in ratios of expected attribute values to the desired ones. These could be computed to quantify quality. Table 2 shows an example for 3 quality characteristics of an idea (notice that functions are not evaluated but characteristics). Each characteristic (cost, emission and operation) can be fulfilled at 3 levels, each obtaining a different score. The total quality score for an idea is calculated by multiplying each characteristic score by its assigned weight (0.3, 0.3 and 0.4 in the example).

The feasibility and/or desired characteristics of each design can be evaluated qualitatively or quantitatively and normalized on a scale of 1 – 10 to get the quality rating show below.

\[
\text{Quality (design)} = \sum_{i=1}^{c} w_i S_i
\]

Where:
- \(S_i\) = the score for the \(i^{th}\) quality characteristic
- \(w\) = the corresponding weight per quality characteristic
- \(c\) = total number of quality characteristics is \(c\).

### Table 2. Quality Score Table

<table>
<thead>
<tr>
<th>Wt.</th>
<th>Quality Score of Design Characteristic</th>
<th>3</th>
<th>5</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>Cost</td>
<td>Too costly, only very few can have it</td>
<td>Approx. 50% of household can afford it</td>
<td>Most households will be able to afford it</td>
</tr>
<tr>
<td>0.3</td>
<td>Emissions</td>
<td>Serious health problems possible</td>
<td>Mild but persistent health issues appear</td>
<td>Can work continuously without health impacts</td>
</tr>
<tr>
<td>0.3</td>
<td>Operation</td>
<td>Very difficult to operate, requires too much attention</td>
<td>Mixed reviews, some users don’t like it, requires some supervision</td>
<td>Very easy, doesn’t require much to get used to it</td>
</tr>
</tbody>
</table>

### Table 3. Pilot Ideation Assignment Data Collection

<table>
<thead>
<tr>
<th>University</th>
<th>Courses (Students)</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>UTEP</td>
<td>MECH 4466 (25)</td>
<td>TRIZ, Sketch Emphasis, Smartpen Use</td>
</tr>
<tr>
<td></td>
<td>MECH 4364 (25)</td>
<td>1 Section Sketch Emphasis, 3 Sections TRIZ, 1 Control</td>
</tr>
<tr>
<td>PSU</td>
<td>EDSGN 100 (120 in 4 Sections) QMM 492</td>
<td>Design Classes are identified but participation details are being confirmed</td>
</tr>
<tr>
<td>Texas A&amp;M</td>
<td></td>
<td>Maryland ENME600 (17) TRIZ Training</td>
</tr>
</tbody>
</table>

### 4 PILOT DATA FROM THREE UNIVERSITIES

The researchers piloted the experiment in selected courses as shown in Table 3. Each University attempted to follow the established protocol for the pilot study. Nevertheless, differences arose that allowed the researchers to review procedures and refine the protocol. In retrospect, the pilot stage data collection cycle allowed the researchers to explore different ways to conduct the experiments and provided interesting variations that are ultimately useful in establishing a unified design of experiment methodology for the four universities.

Ideation Assignment (design task) employed in this pilot study reads as follows:

*In rural areas of developing countries, such as Kenya, cooking is done in the home with biomass type cooking systems. One of the adverse affects of these cooking systems is the emissions which cause respiratory illnesses for millions of children and women. The people in these developing countries are economically and culturally constrained by the types of cooking systems they use. Also, depending on the type of biomass used there can be unsustainable and detrimental effects on the environment. Develop several concepts for a cooking system that is culturally appropriate, sustainable and low cost to meet the needs of rural Kenya.*

#### 4.1 Penn State Pilot Data

At Penn State, data collection plan provided in Table 3 has been implemented in two different courses: EDSGN 100, and QMM492. Four sections of the EDSGN 100 course were involved in data collection yielding over 120 individual data points and 32 team level data sets. Out of these sections, three of them were taught by the same instructor. In two sections (where TRIZ training was provided), instructors were different, and the level of the bias introduced due to having different instructors was intended to be measured. In QMM492 (TRIZ intervention), a senior course for non-engineering students, data was collected to be compared to senior engineering students to understand the importance of the background knowledge of students.
Researchers administered the treatments and Ideation Assignment as required by the protocol. The researchers collected and organized the solution concepts generated by the students for the Ideation Assignment into three functional categories: Energy Source and Fuel, Function and Body Design. Three indices were used to quantify the ideation performance of the students, novelty, variety, and quantity. The results at the functional level (not in synthesized designs) are given below.

Table 4. Novelty Metric Table for Energy Function of the Sketch Emphasis Class

<table>
<thead>
<tr>
<th>Energy Source &amp; Fuel</th>
<th>C</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 Solar energy</td>
<td>7</td>
<td>7.4</td>
</tr>
<tr>
<td>A2 Human energy (Crank)</td>
<td>1</td>
<td>9.6</td>
</tr>
<tr>
<td>A3 Wood</td>
<td>4</td>
<td>8.5</td>
</tr>
<tr>
<td>A4 Wind</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>A5 Alcohol</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>A6 Chemical</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>A7 Dung</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>A8 Natural gas</td>
<td>3</td>
<td>8.89</td>
</tr>
<tr>
<td>A9 Electricity</td>
<td>6</td>
<td>7.78</td>
</tr>
<tr>
<td>A10 Fuel</td>
<td>4</td>
<td>8.51</td>
</tr>
<tr>
<td>A11 Biomass</td>
<td>1</td>
<td>9.6</td>
</tr>
<tr>
<td>A12 Battery powered</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>A13 Mirror reflect</td>
<td>1</td>
<td>9.6</td>
</tr>
<tr>
<td><strong>Novelty</strong></td>
<td></td>
<td><strong>17.09</strong></td>
</tr>
</tbody>
</table>

Table 5. Summary of Pilot Data from Penn State

<table>
<thead>
<tr>
<th>Engineering Design 100 Sections</th>
<th>QMM 492</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sect. 11</td>
<td></td>
</tr>
<tr>
<td>Sect. 15</td>
<td></td>
</tr>
<tr>
<td>Sect. 6</td>
<td></td>
</tr>
<tr>
<td>Sect. 16</td>
<td></td>
</tr>
<tr>
<td>Sketch Emphasis</td>
<td></td>
</tr>
<tr>
<td>Control Group</td>
<td></td>
</tr>
<tr>
<td>TRIZ Design Method</td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Variety Index Table for the Fuel Function Category of the Sketch Emphasis Section (with n =13)

<table>
<thead>
<tr>
<th>Section</th>
<th>S</th>
<th>B</th>
<th>S*B</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Level</td>
<td>5</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>Second Level</td>
<td>2</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td><strong>Variety Index M</strong></td>
<td></td>
<td>2.38</td>
<td></td>
</tr>
</tbody>
</table>

The Penn State data indicate mixed results. For the Functionality and Energy Source & Fuel functional categories, the Control Group metrics top other groups, except for the Section 16 TRIZ-trained group on Functionality. The results for Novelty in the Body Designs are improved by the Sketching Emphasis and TRIZ treatments. These results require investigation.

Figure 3. The Hierarchy Structure of the Fuel Function of the Sketch Emphasis Section

Table 4 is the energy source and fuel category from the Sketch Emphasis class. The fuel function includes n =13 concepts related to the way of generating energy. In the Sketch Emphasis class, students generated a total of 27 ideas related to all the 13 concepts. Thus, we have \( \sum_{i=1}^{13} C_i = 27 \). Take A1, the solar energy concept as an example. The novelty value (S) value for solar energy (A1) is \( S_i=(27-7)/27=7.407 \). To aggregate into the novelty index for fuel function, we multiply \( C_i \) with \( S_i \) for each concept and then sum. Next, we divide the obtained sum by the number of concepts (\( n \)), where \( n = 13 \) for the energy source and fuel function.

The variety computation is presented here for the same example. Figure 3 shows the hierarchy of the energy source and fuel function for the Sketching Emphasis Condition class. For the example, there are two levels, three working principles and eight effective concepts. Thus, we have \( p = 2, B_1 = 3, B_2 = 8, \) and \( n = 13 \). Since the sum of \( f \) equals 1, we can have the variety index for this fuel function \( M = 1*(5*3 +2*8)/13 = 3.00 \). Table 6 shows the information for the calculation of this variety index.

The Penn State data indicate mixed results. For the Functionality and Energy Source & Fuel functional categories, the Control Group metrics top other groups, except for the Section 16 TRIZ-trained group on Functionality. The results for Novelty in the Body Designs are improved by the Sketching Emphasis and TRIZ treatments. These results require investigation.
4.2 UTEP Pilot Data

The pilot study performed at UTEP in the fall semester of 2009 found that the treatment for TRIZ and Smartpen can be complex. Students were trained on the use of TRIZ, and they were required to first produce a function diagram, define the technical contradictions and produce concepts as part of their ideation assignment.

It was clear that the students were interested in the TRIZ method, but required more than the 2 hours originally allocated for the training and initial ideation session. With respect to the Smartpen, students were excited to learn about this new technology, but it was clear that the immediate benefit was the eagerness to use it. The pen stores anything written and the audio conversations, but this functionality is most useful for design tasks over longer periods of time when students need to revisit their ideation sessions. In this pilot study, introduction of the Smartpen to enhance sketching was the easiest variable to manipulate.

Results in Table 7 indicate that TRIZ improved Novelty and Variety scores when compared to the control group. Other results may not be reliable considering that this was a pilot study conducted with the objective of learning about possible experimentation approaches.

Table 7. Summary of Pilot Study Data from UTEP

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Quantity</th>
<th>Quality</th>
<th>Novelty a Priori</th>
<th>Novelty a Posteriori</th>
<th>Variety (M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRIZ</td>
<td>1</td>
<td>5.30</td>
<td>5.80</td>
<td>6.60</td>
<td>5.10</td>
</tr>
<tr>
<td>Sketch Emphasis</td>
<td>1</td>
<td>4.38</td>
<td>4.32</td>
<td>1.54</td>
<td>2.10</td>
</tr>
<tr>
<td>Smartpen</td>
<td>1</td>
<td>4.80</td>
<td>4.35</td>
<td>4.66</td>
<td>2.30</td>
</tr>
<tr>
<td>Control Group</td>
<td>1</td>
<td>5.40</td>
<td>2.40</td>
<td>3.00</td>
<td>1.20</td>
</tr>
</tbody>
</table>

4.3 University of Maryland Pilot Data

A group of 17 University of Maryland graduate students participated in a pilot study of the TRIZ intervention. The course was “Engineering Design Methods” (ENME 600), an introduction to different conceptual design methods for mechanical engineering. Seven of the students were also working engineers. Fourteen class members had never heard of TRIZ before the experiment. The other three (two professionals and one student) were more familiar with TRIZ (i.e., they rated their understanding of TRIZ at a level of “3” out of 5).

The 17 class members were in the TRIZ training condition; the class members were not given the sketching emphasis lecture and they did not use the Smartpens for their sketching. The same ideation assignment used at other the Universities was used for this group, with the exception that students were asked to take the assignment home and complete the TRIZ application through to the development of one or two good solutions. During the 20 minutes in-class experiment time most of the class was able to identify proper contradictions and suggested inventive principles for application to the design task but they did not complete a design solution until they were able to spend additional out of class time on the design exercise.

The computation process for the Variety Index, as demonstrated with the Penn State data in Section 4.1.2, is shown. Figure 4 shows the genealogy tree for the UMD Class that was given the TRIZ training. In the UMD data there are two levels, three working principles (combustion, electricity, and power plant), seven effective concepts for these principles, and 16 solutions were generated. Thus, for this example, we have $p = 2$, $B_1 = 3$, $B_2 = 7$, and $n = 16$. Following the calculations in Table 6, the variety index for this function is $M = 1*(5*3 +2*7)/16 = 1.813$.

4 PRELIMINARY OBSERVATIONS

The observations from the pilot run of this study are mainly logistical in nature. Overall, these observations reflect the complexity of collecting data in classroom settings, and across locations. Our preliminary plans to ameliorate the experimental design and processes are also provided.

- Problem ambiguity
  Participants commented that the description and the goal of the problem were not very clear. The problem wording could be modified to make the assignment more clear. It should be stated that any energy method can be used to cook although biomass or any culturally appropriate method is preferred.

- Restricted DOE
  Treatment, runs, training, evaluation and every stage of the DOE was fixed without considering if it was the optimal condition. For example, TRIZ intervention required more training and time than the other treatments, which was not originally foreseen. Taking lessons learned from the pilot experiments we can optimize the stages to obtain better of treatments. Clarity in each stage for all the parts will improve performance.
- Statistical significance
  The objective of the experiment is to conclude if the treatment improves the creativity in the students. Due to variability we need to evaluate if the results have statistical significance. In this pilot study, the sample size is not adequate for statistical conclusions but effect sizes can be calculated and used to estimate required sample sizes for statistical significance. Required sample sizes will be calculated.
- Variability in procedure between universities
  Each university followed a slightly different procedure for the experimental conditions. Differences between universities should be only a result of the students’ background, not DOE factors (e.g., common treatments, training, scoring, etc.).
- Only four metrics used for scoring
  A lot of information about the ideation methods process was missed in the runs. To understand better the origin of the scores of each treatment and understand the ideation process better we need to add metrics to the experiment.
- Granularity in the metric-based results
  For the evaluation of the results, (without consulting one another), UTEP members implemented metrics at the complete concept level while the Penn State members opted for functional level data. Both of these granularity levels, and their implications should be explored.
- Motivation
  To eliminate a potential lack of motivation in the participants, extra points were given to the participants at one of the universities. However, extra points were not linked to effort or quality. Linking the extra points to final grade or awards could be possible solutions for this problem. Motivation is important because it will give us the maximum result without the implication of some creative and some not creative participants.

These conclusions were derived from conducting the pilot study at different Universities. The data and analysis provide a variety of perspectives that will be useful in defining a unified approach for the next round of experiments in this project.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of the National Science Foundation grant. The project is funded by NSF grant CCLI-II 0920446. The opinions expressed in this paper do not necessarily reflect those of NSF. The authors also acknowledge the student participants in the pilot studies.

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