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Creativity Enhancement via Engineering Graphics: Conceptual Design Blending Approach

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Introduction

Creativity remained a relatively neglected topic in research until J.P. Guilford proposed a psychometric approach in 1950 to study creative thinking in a population that is not exclusive to artists or scientists. [1] Creativity is important in engineering because of the "growing scope of challenges ahead and the complexity and diversity of 21st century technologies." [2] Despite the increasing demand of creative thinking in Science, Technology, Engineering, and Mathematics (STEM), business, agriculture, global market and economy, not much has been done to develop a creativity-enhanced curriculum in institutional education. [3] One of the main reasons behind this is the diversity of definitions and criteria for creativity that makes it either intangible or insignificant. Historically, we have classified creativity as an innate quality, a divine intervention that only a fortunate few of us seem to experience. [1] This mystical approach makes it difficult to think that creativity can be taught and learned. However, extensive research on creative ability has led to different creativity theories showing that creativity is not a fixed trait. In fact, Epstein's Generativity theory suggests that every individual has limitless creative potentials, which are not expressed frequently as our culture tends to discourage such expression. [4] He mentions four essential competencies for creative expression that are measurable and trainable: [5]

- *Capturing:* recording new ideas as they occur
- *Challenging:* taking on tasks that require individuals to step out of their comfort zone
- *Broadening:* "seeking training, experience, and knowledge" outside current field of interest
- *Surrounding:* being conscious of the physical and social environments and changing them frequently to find unusual inspirations

Creativity, especially in engineering, is viewed as the ability to experiment, take risks, push boundaries, recognize patterns, and examine problems from different perspectives. Recent research analyzing 300,000 scores of children and adults on the Torrance Test of Creative Thinking has discovered that creativity scores have been declining since 1990. [6] Hence the question arises, how can we develop a curriculum that would encourage and improve students' creativity? Additionally, Kazerounian and Foley [7] showed a valid argument for the importance of creativity in engineering as well as a lack of techniques to foster it in our engineering students. Thus, an engineering professor at a western university developed a pedagogical approach to engineering graphics instruction called *Conceptual Design Blending (CDB)* that facilitates creativity in engineering students. The term CDB has its root in Fauconnier and Turner's Conceptual Blending [8] and Arthur Koestler's Bisociation [9] where students are asked to generate an entirely new design using features of two or more pre-existing designs. [10] With regard to CDB, as defined by Bell et al.:

> "CDB is itself a conceptual blend of Conceptual Blending and Shape Blending into something new. Once the foundational techniques of the 3D CAD software have been taught, the CDB pedagogy deviates sharply from traditional instruction. Rather than assigning designs to replicate, the instructor presents students with two or more seed

> designs, and instructs them to design something entirely new based on those concepts, but with functionality and/or aesthetic appeal beyond either seed design. Since students are initially unsure of themselves, and do not know where to start with such open-ended requirements, the instructor introduces CDB by walking through examples of blending and presenting multiple think-aloud illustrations of the design process. Throughout the instruction, students are reminded that they each have unique and useful ideas to contribute, and are encouraged to borrow ideas from other places, provided the ideas are used within a design rather than strictly copied." [10]

This teaching technique was developed under a belief that when students have the "free-form ability" to create or solve open-ended problems in a solid modeling course, it eradicates inhibitions and boosts creativity. Part of the motivation behind the technique is to incorporate more of the arts into engineering, as the originator, John Devitry-Smith, had personal experience with the arts promoting his academic motivation and eventual career in engineering. The present paper reports on an experimentally designed study that investigated whether the CDB approach enables students to improve their creativity as measured with the Abbreviated Torrance Test for Adults (ATTA).

Methodology

Researchers collected data from four sections of an engineering graphics class taught by a professor at a western university. This research follows a full experimental design where each class section is considered as one sample, rather than the quasi-experimental approach of counting each measurement unit (i.e. participant) as an experimental unit. By counting only one experimental unit per application of treatment (i.e. delivery of either the traditional or CDB instruction), the tendency toward overoptimistic analysis that is typically the result of treating measurement units as experimental units will be avoided. [11] Therefore, the four class sections created a sample size of 4. Sections were divided into two experimental and two control groups through stratified random sampling. The researchers randomly chose one large section (> 40 students) and one small section (< 25 students) to receive CDB instruction. The other two sections, one large and one small, received traditional instruction. Students did not have any prior knowledge about the decision, and were not aware of the study at the time of enrollment. They also did not know about the difference in treatments throughout the semester although data are only reported from students who agreed to participate in the study. The instructor invested equal amount of time, effort, and enthusiasm in both groups. Siemen's 3-D design software called Solid Edge was used as a solid modeling platform. Its synchronous technology capabilities for interacting with a solid model proved beneficial for this type of teaching intervention. Within the first 6 weeks of the semester all sections learned the basic operations of the software. During the later half of the semester, the experimental and the control groups received differentiated instructions on complex modeling and simulation. At this point, the CDB was introduced.

Approximately 25% of the students from each section were randomly selected for the ATTA to measure their creative ability. Students took the pre-ATTA during the 7th week and the post-ATTA during the 14th week of the semester. The 7-week time span was considered sufficient to reduce any practice effects on the post-ATTA score. [12] Attrition between pre and post-test was less than 20%. However, it did not seem to affect the study results since mortality rates were comparable between both treatments. The rest of the students completed other metrics not related to creativity.

The Torrance Test

Numerous creativity instruments have been developed over the years that measure creative performance based on different criteria. For example, the Khatena-Torrance Creative Perception Inventory, a self-ranked measure studying creativity as a personality trait, refers to individuals' perception of their own creativity and capability for creative expressions. [1] The Epstein Creativity Competencies Inventory for Individuals (ECCI-i) is another self-ranked test that measures basic competencies essential for creative expression. [5] The ECCI-i differs from personality tests in the sense that it measures skills that can be improved easily through training and practice. The Guilford's Alternate Uses Test measures participants' divergent thinking where participants are asked to record as many applications for a common household item as possible. [13] The Abedi-Schumacher Creativity test is a multiple-choice paper-and-pencil test where students self-rank 60 questions that are considered as indicators for fluency, originality, elaboration, and flexibility. [14]

Dr. Paul Torrance developed the Torrance Test of Creative Thinking (TTCT) in the mid-1960s where divergent thinking is considered the foundation of creativity. It measures creativity from a psychometric standpoint, and has been the most widely used test to assess creativity. [6] The TTCT consists of one verbal and one non-verbal section. Due to long testing time (45 minutes for verbal and 30 minutes for non-verbal responses), Torrance thought a shortened version would be practical and effective, especially for adults. Torrance and his colleagues created the Demonstration Form of the Torrance Test (DFTT), which had enough success to warrant the development of the ATTA. The ATTA was chosen for this study due to its delivery time (15 minutes) and its reliability and validity (ATTA creative ability score: $r = 0.59$ [adjusted $r = 0.70$], $p = 0.006$; ATTA creativity level score: $r = .56$ [adjusted $r = 0.66$], $p = 0.011$). [15]

The ATTA consists of three activities. One activity asks for verbal responses and the others two call for figural responses. It measures four subskills of an individual's creative ability: Fluency (number of ideas/designs), Originality (number of unique ideas/designs), Elaboration (number of details to embellish an idea/design), and Flexibility (number of different ideas/designs). [16] The test also provides 15 criterion-referenced creativity indicators for verbal responses (richness and colorfulness of imagery, emotions/feelings, future orientation, humor: conceptual incongruity, and provocative questions) and figural responses (openness: resistance to premature closure, unusual visualization, movement and/or sound, richness and/or colorfulness of imagery). It has a shorter administration time of 3 min./activity that must be strictly followed.

Grading and Inter-rater Reliability

The ATTA has some grading requirements that can be slightly subjective. The Scholastic Testing Service, Inc. provides a rubric and allows for researchers to evaluate their own test results. For this reason inter-rater reliability with more than one grader was important. Both the pre-test and post-test were graded individually for all ATTA recipients in each of the 4 classes by two graders. The grading was accomplished and discussed as a team during the first five tests scored, assuring that graders were following the ATTA grading manual strictly and that graders were consistent regarding their understanding of the grading instruction. Additionally, one other member of the research team graded three of the exams and arrived at nearly the same results prior to the full grading analysis. The inter-rater reliability test for the 4 samples yielded a correlation of 0.979 for the pre-test scores and 0.984 for the post-test scores between two-raters with a 0.00 p-value for both scores. For this study, the creativity index (creative abilities + creative indicators) was used instead of the creativity level as it provides more range to observe the effect of CDB on creativity. The two graders' scores on each student's creativity index were averaged in order to have a single pre-test and post-test score for each participant.

Results and Discussion:

Table 1 shows the data for both pre-ATTA and post-ATTA creativity index, and the increase in the creativity index. The creativity index for each class was calculated by averaging the individual creativity measures, as assessed by both graders, for each section. As the tabulated data indicates, the experimental groups that received the CDB instruction increased more than twice as much in creativity index compared to the control groups that received traditional instruction. Three statistical approaches were used to analyze the data: a t-test on the increase in ATTA creativity index, one-way ANOVA, and Cohen's D test. All analyses were performed in R. The pre-ATTA score was subtracted from the post-ATTA score to determine the increase ATTA score for each class. The unpaired t-test, the most direct measure that the hypothesis is true, revealed a borderline significance of 0.05. The one-way ANOVA of the post-ATTA score and CDB treatment highly suggested a link between the ATTA score and the CDB instruction ($F(1, 2)= 18.3$, $p= 0.05$).

Table 1: Average pre-ATTA and post-ATTA creativity index, and increase in the creativity index

		n	Pre-ATTA	Post-ATTA	Increase ATTA
CDB Treatment Group	Class 1	10	68.5	74.35	5.85
	Class 2	3	66	73.67	7.67
Control Group	Class 3	7	57.5	57.29	-0.214
	Class 4	10	66.6	63.6	-3

The one-way ANOVA of the increase in ATTA score and CDB treatment yielded the following results: The difference in average score increase between treatments is statistically significant ($F(1, 2) = 25.3$, $p = 0.037$), with the increase after the CDB treatment being greater. 93% (R^2) of the variability of the response data around its mean is explained by the selection of the treatment. The Cohen's D = Infinite, with a Cohen's D value ≥ 0.4 indicating a larger effect size. The Cohen’s D value for this test suggests that the CDB instruction has a greater effect on the increase in ATTA score compared to conventional instruction. As mentioned above, each participant is treated as a measurement unit and each section is treated as an experimental unit (quantitatively represented by the average of that experimental unit’s measurement units) in order to avoid overoptimistic results. [11] Clearly, the sample size of 4 for this study is the absolute recommended minimum for comparing a treatment and a control.

In considering the source of the impact from CDB, there are four factors that stand out that may separately find application in an engineering graphics course. 1) The requirements for the project were open-ended, 2) Students were encouraged to create unique objects, rather than copy an example design, 3) Students were forced to consider the internal features and meshing approaches of multiple objects that normally would not be combined, and live examples of the thought process were provided, and 4) Students were encouraged to think of engineering graphics as an aesthetically-pleasing production.

Limitations and Recommendations

As an initial study that developed pilot data, this research had a small dataset of only 4 samples. More samples would be ideal. For this study, the same instructor was used for all four sections – which was necessary to avoid confounding factors in looking at the results. However, for better insight into the general applicability of the CDB teaching approach, data should be collected from other instructors as well. These four samples generally had students who were ethnically, socially, and culturally similar within this institution’s typical demographic. The majority of the students were white and hailed from the same geographical region of the U.S. Also, there was not much gender diversity within the engineering classes studied. Students were predominantly male. This study also did not track the long-term effect of the CDB instructions on students’ creativity. However, the significant effect of CDB on creativity indicates that additional research should be conducted addressing the limitations of this initial study. It would be worthwhile to investigate the long-term effect of the CDB treatment on students’ creative performances in other courses and later in their career. Also, the CDB instructions in this study were developed particularly for engineering undergraduate students. Future research should be conducted on to develop a CDB instruction-based curriculum for other fields as well. A strong possible impact area or CDB may also lie within lower grade levels found within secondary and middle schools. Expanding this research into other learning environments is certainly worthwhile.

Additionally, other studies regarding the integration of the arts into STEM may gain insight through a similar investigation. Such efforts – to include the arts in STEM, creating STEAM – have gained general recognition. [17] While much of the impact of the arts is qualitative in nature, if investigations into these efforts can identify quantifiable impact, it may help justify their expansion.

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