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Pre–Post Assessment of Creativity Methods in an Experimental Course*

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This paper compares performance and creativity of design projects before (pre) and after (post) students apply creativity methods taught to them in an experimental course. Design projects are evaluated by numeric performance scores and qualitative Creative Product Semantic Scale (CPSS) scores. A preliminary pre–post analysis of design projects indicates that the creativity of the projects improves after applying creativity methods; however, a more creative project does not necessarily improve performances after applying creativity methods. CPSS 'resolution' scores and 'elaboration and synthesis' scores are good measures of project performance; however, CPSS 'novelty' scores do not have significant associations with performance scores. Projects with simpler designs perform better, which is suggested by a significant negative association between part counts and performance scores.

Keywords: creativity; evaluation; decision making; design education

1. Introduction

Teaching creativity is often considered one of the main objectives of engineering education [1, 2]. Teaching creativity methods is important in engineering design courses, as design is often viewed as a thought process of generating, evaluating, and specifying concepts while satisfying constraints [3, 4]. The use of metaphor has been shown as a successful creativity approach for innovations. Using the metaphor of 'theory of automobile evolution,' Honda predicts a next-generation automobile to evolve towards a spherical shape. Based on the prediction, Honda develops Honda City, a model that is shorter and taller than their popular Civic and Accord models [5]. Similarly, analogies in nature and other artifacts have been cited as source of innovations. For example, Pringles potato chips are invented from an analogy to nature (i.e., wet leaves) [6], and a seeding device that secures a certain space between seeds is invented from an analogy to machine-gun ammunition belts [6].

Many creative methods have been proposed for problem solving [7, 8], and some of these methods have been implemented in design. Creativity methods that have been used in design courses may be classified into methods that use information internal or external to designers: examples of the former type of methods include brainstorming [9], mind maps [10], metaphor [5, 11], and morphological analysis [12]; and examples of the later include analogy [6, 11] and theory of inventive problem solving (TRIZ) [13]. The former methods are typically taught as essential methods in design texts and in design courses [12, 14]; however, more systematic creativity methods using TRIZ has increasingly been studied [15, 16] and incorporated in design curricula [17, 18].

While no designer may doubt the benefits of creativity methods, research on the effects of creativity methods is relatively new. To evaluate creativity methods, Shah *et al.* [19, 20] proposed four metrics: Novelty, Variety, Quality, and Quantity. Except for Quantity, which is defined as the number of concepts, these metrics are calculated based on information obtained from concepts and prototypes generated as the result of using creativity methods. For example, Novelty, Variety, and Quality are calculated from weights of product functions (or product characteristics) and scores of each concept (or prototype) evaluated on these functions.

In contrast to evaluating creativity methods, Besemer and O'Quin [21] develop and validate a Creative Product Semantic Scale (CPSS) that can be used to evaluate creative products (artifacts). The CPSS consists of 70 bipolar semantic scales answered on a seven-point scale. O'Quin and Besemer [22] revise the CPSS by reducing the number of bipolar semantic scales to 55. The revised CPSS consists of three scales that represent conceptual dimensions: Novelty, Resolution, and Elaboration and Synthesis. Novelty is the newness of processes, materials, and design; Resolution is the functionality, usefulness, and workability of the product; and Elaboration and Synthesis are the stylistic attributes of the finished product [21]. These scales consist of 11 subscales that describe attributes of creative products: Original, Surprising, and Germinal as subscales of Novelty; Valuable, Logical, and Useful

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as subscales of Resolution; and Organic, Elegant, Complex, Understandable, and Well-crafted as subscales of Elaboration and Synthesis. Each of these 11 subscales consists of five bipolar semantic scales rated on a seven-point scale. Thus, there are a total of 55 bipolar semantic scales: 15 bipolar scales for Novelty, 15 bipolar scales for Resolution, and 25 bipolar scales for Elaboration and Synthesis. If an evaluator is asked to rate the newness–oldness of a product, he or she assigns a number between 1 and 7 on the following scale, where 1 is new and 7 is old: New 1—2—3—4—5—6—7 Old.

In contrast to creating metrics to evaluate creativity methods or creative products, Yang and her colleague study creativity processes. Yang [23] studies student design projects and finds that prototypes with fewer part counts perform better in the final design contest. Yang and Cham [24] find that the number of sketches does not correlate with design outcomes. On the other hand, Yang [25] finds that the number of brainstormed ideas and morphological alternatives significantly correlates with design outcomes.

While many research projects study creative processes and outcomes (sketches and prototypes) by comparing control and treatment groups, another approach that has been used in past studies is to compare the same group before (pre) and after (post) a treatment. This pre–post assessment has been used to evaluate the effects of a creativity training [26] and creativity workshops [27].

This paper compares performance and creativity of design projects in an experimental course before (pre) and after (post) applying creativity methods. In the first year of the experimental course, the CPSS is tested on whether it can be used to evaluate design projects. In the second year of the experimental course, design projects before (pre) and after (post) applying creativity methods on the same design task are evaluated by numeric performance scores and CPSS scores. Section 2 presents a design project and creativity methods employed in the second-year experimental course. This is followed by Section 3, which presents pre–post analysis of design projects; Section 4 explores whether or not students' risk attitudes can explain project performance and creativity outcomes, and Section 5 summarizes the findings with discussions of the limitations of the findings and future work. Section 6 concludes the paper.

2. Design project and creativity methods

An experimental course to teach creativity methods and creativity blocks and to implement creativity methods in design projects is offered twice. In the first offering, nine students register for the course and they are grouped into three teams of three students. The final design project is to create a new toy for children. Three final projects are evaluated by final project report scores and CPSS scores. The overall CPSS scores are calculated from the individual CPSS scores by taking the average of 55 CPSS scores. The correlation between the project report scores and the overall CPSS scores of three projects is 0.956, which is sufficiently large.

In the second offering, three students register for the course and individually work on simple creativity projects (a repetition of a same project before and after creativity methods in order to enable pre–post analysis) and the final design project. The focus of this paper is the pre–post assessment of the creativity project. The creativity projects are intended to provide immediate feedback on the benefits of the creativity methods. The creativity project is assigned on the first day of the class, and is due in two weeks. The project is to create a device that launches a ping-pong ball as far as possible, in which the performance of a project is measured by the average distance of five ping pong balls launched. Project specifications are as follows:

- Fits within the volume of 10 inches wide × 10 inches deep × 10 inches high
- Uses only mechanical energy
- Uses materials available in general stores (i.e., cannot use off-the-shelf assemblies)
- Cannot use manual interaction except for loading the ball onto the device and activating the device.

Until the project testing day, students are not given lectures on creativity methods. Each project is tested individually so that students do not know what other students create. After the first design projects are tested, students are assigned the same design task again; however, in the second design project, students are asked to apply the creative methods in Table 1.

Before starting the second design project, creativity blocks [28] are discussed and students first establish functions of the device using a Function Analysis System Technique (FAST) [14, 29]. Students individually create FAST diagrams and then integrate their FAST diagrams to construct the overall FAST diagram. In addition to higher-order function (launch ping pong ball) and assumed function (provide energy), three critical path functions (store energy, release energy, and release ping pong ball) and three supporting functions (accept mechanical energy, transmit energy, and hold ping pong ball) are identified as the functions in the project domain.

Before generating ideas for their projects, brainstorming [9] is explained in order to emphasize the importance of creating wild ideas and avoiding idea

Table 1. Creativity methods

	Process	Methods
1.	Functional analysis	Function Analysis System Technique
2.	Idea generation	Mind map Analogy (natural systems) Analogy (physical systems)
3.	Idea synthesis	Morphological analysis

evaluation at this stage. Then, each student individually creates mind maps [10] for each of the six functions. In addition to six mind maps (one for each function), each student generates six lists of solutions applying analogy to nature and six lists of solutions applying analogy to artifacts. At the end of this idea generation stage, each student has six mind maps, six lists of analogy to nature, and six lists of analogy to artifacts.

Using the mind maps and the lists of analogies, each student creates three morphological matrices [12] in the next step. The first morphological matrix is created by selecting five solutions for each function from the mind maps (i.e., five solutions from each of the six mind maps); the second morphological matrix is created by selecting five solutions for each function from the lists of analogous natural systems; and the third morphological matrix is created by selecting five solutions for each function from the list of analogous physical systems.

Using these morphological matrices, students create five concepts using at least each morphological matrix once and by combining at least one solution from each row of a morphological matrix.

Once five concept sketches are generated based on solutions combined in the morphological matrices, students individually construct objectives trees [12] to identify concept evaluation criteria and their weights, and decision matrices [12] to select one of the five concepts. The device of the selected concept is constructed and tested.

3. Pre–post comparisons

Six devices in Table 2 (three devices before and three devices after applying creativity methods) were constructed and evaluated for their performances (the average distances of five ping pong balls) and their creativity using the revised CPSS [22]. Table 3 summarizes four design characteristics of these projects: types of energy used for launching ping pong balls, components used to store energy, approaches to transfer energy to ping pong balls, and the number of components.

Project 1 before creativity methods (Pre-1) used the tension of a spring to shoot a ping pong ball. Project 1 after creativity methods (Post-1) was primarily an extension of the project before creativity methods; the only difference was the use of compression instead of spring tension as the energy source. This design change enabled the project to use a stronger spring and to withstand a higher potential energy accumulation. As discussed later, this change improved the project performance, but only slightly improved creativity. The number of parts used in the project decreased from 39 before creativity methods to 20 after creativity methods.

Project 2 before creativity methods (Pre-2) also used the tension of springs to shoot a ping pong ball. Project 2 after creativity methods (Post-2) still used the tension of springs as the energy source; however, it hit a ball in a manner similar to that in golf instead of shooting the ball. This design change improved both performance and creativity, as discussed later. The number of parts used in the project decreased from 33 before creativity methods to 19 after creativity methods.

Project 3 before creativity methods (Pre-3) used the tension of elastic bands to launch a ping pong ball. The design of the project after creativity methods (Post-3) completely changed. Instead of using the tension of the elastic bands, the project used a momentum of a flywheel as a kinetic energy source.

Table 2. Projects before and after creativity methods

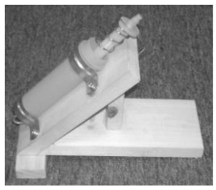
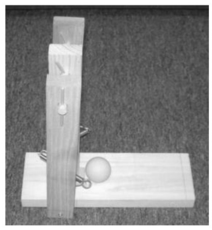
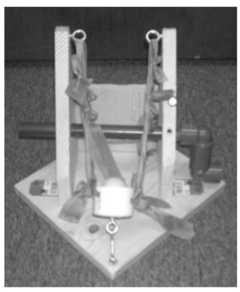
Project	Pre	Post
1.		
2.		
3.		

Table 3. Design characteristics of projects before and after creativity methods

Project	Design characteristics	Pre	Post
1	Energy	Potential	Potential
	Energy source	Spring—tension	Spring—compression
	Energy transfer	Push	Push
	Part count	39	20
2	Energy	Potential	Potential
	Energy source	Spring—tension	Spring—tension
	Energy transfer	Push	Hit
	Part count	33	19
3	Energy	Potential	Kinetic
	Energy source	Rubber band—tension	Flywheel—momentum
	Energy transfer	Push	Push
	Part count	42	80

This design change significantly improved creativity; however, the performance worsened, as discussed later. The number of parts used in the project increased from 42 before creativity methods to 80 after creativity methods.

Figure 1 compares performances (average distances) and creativity of the projects before (pre) and after (post) applying creativity methods. Creativity is measured as averages of 15 ratings of the bipolar semantic scales of *Novelty*, 15 ratings of *Resolutions*, and 25 ratings of *Elaboration and Synthesis*.

The performance of Project 1 after creativity methods (Post-1) improved, as the average distance of ping pong balls increased from 5.8 meters to 12.1 meters; however, creativity improved only slightly. The performance of Project 2 after creativity methods (Post-2) increased, as the average distance of ping pong balls increased from 0.9 meter to 6.7 meters; however, the performance was not as good as that of Project 1 after creativity methods (Post-1). On the other hand, creativity significantly increased after applying creativity methods. The performance of Project 3 after creativity methods (Post-3) decreased as the average distance of ping pong balls decreased from 5.5 meters to 1.3 meters; the CPSS Novelty scores improved, while both the CPSS Resolution and Elaboration and Synthesis scores decreased.

Figure 2 compares the creativity of projects before and after applying creative methods by average ratings of the following CPSS subscales: Original, Surprising, and Germinal of *Novelty*; Valuable, Logical, and Useful of *Resolution*; and Organic, Elegant, Complex, Understandable, and Well-crafted of *Elaboration and Synthesis*. The CPSS scores of Project 1 before (Pre-1) and after creativity methods (Post-1) were essentially the same. The average rating of all subscales were larger than 4 (i.e., better than the neutral) except for Complex, which indicates that the designs of the projects were simple.

The CPSS scores of Project 2 before (Pre-2) and after creativity methods (Post-2) were significantly different. Before creativity methods, only the Understandable subscale was larger than 4. After creativity methods, all subscales except Complex were larger than 4. This indicates that the design of

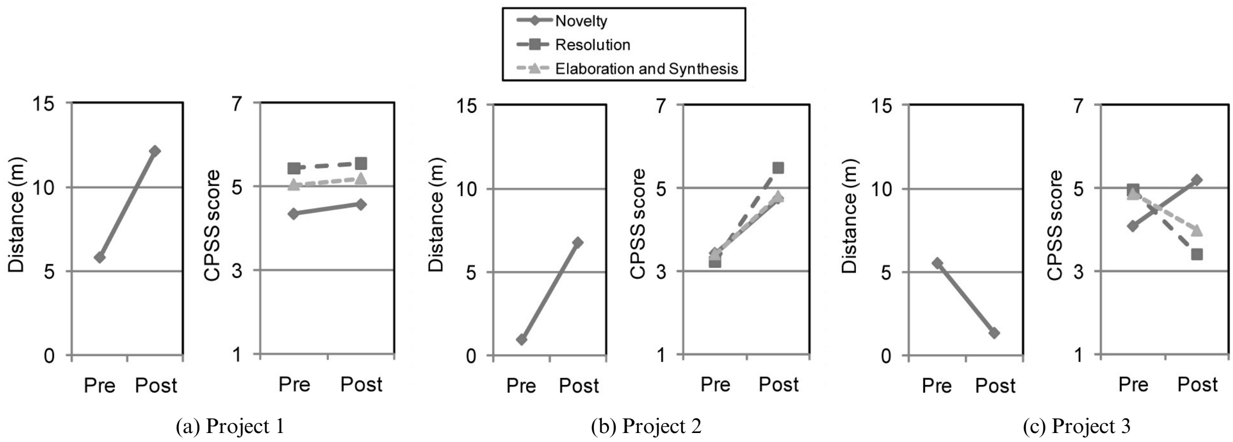
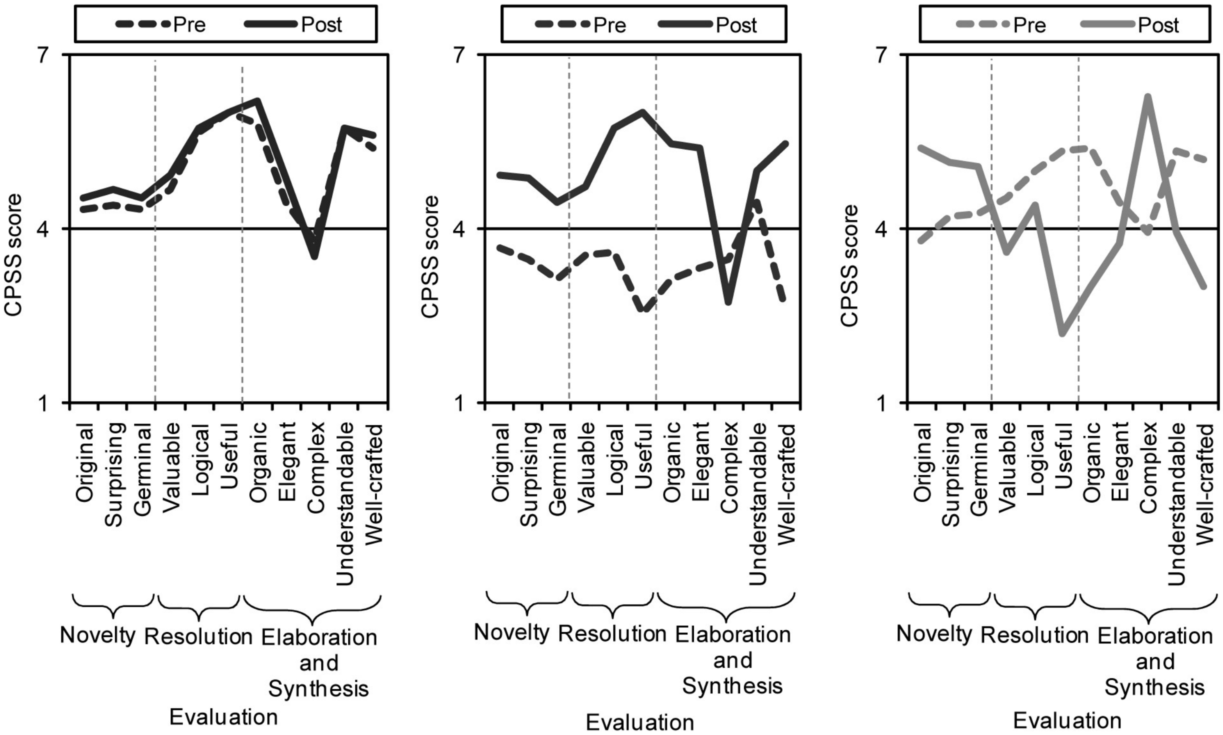
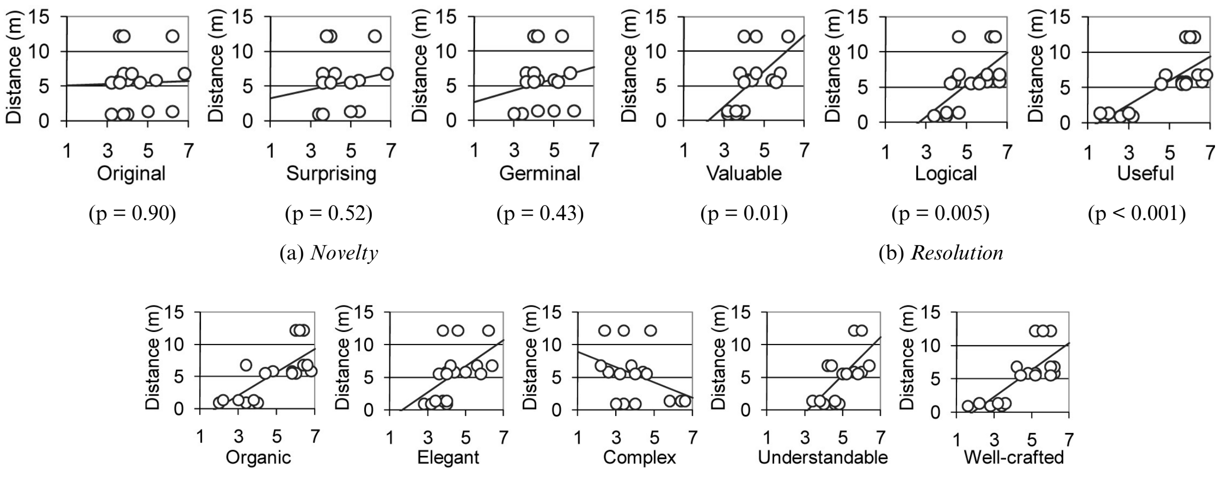


Fig. 1. Pre–post comparisons of performance and creativity.



(a) Student 1 (b) Student 2 (c) Student 3

Fig. 2. Pre–post comparisons of creativity.



(p = 0.90) (p = 0.52) (p = 0.43) (p = 0.01) (p = 0.005) (p < 0.001)

(a) *Novelty* (b) *Resolution*

(p < 0.001) (p = 0.02) (p = 0.096) (p = 0.004) (p < 0.001)

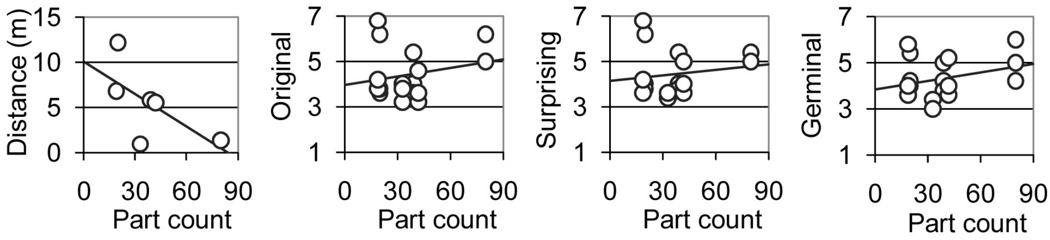
(c) *Elaboration and Synthesis*

Fig. 3. Regression analysis of the average distance versus secondary CPSS scores.

the project was assessed as more novel and useful and, at the same time, simpler after creativity methods.

The CPSS scores of Project 3 before (Pre-3) and after creativity methods (Post-3) also changed significantly. Before applying creativity methods, all subscales were above 4 except Original and Complex, which were slightly below 4. After creativity methods, all Novelty subscales (Original, Surprising, and Germinal) and the Complex subscale increased, and all other subscales decreased. This implies that, while the project was more creative after applying creativity methods, it was also more complex.

Figure 3 summarizes a regression analysis of 18 data (six projects evaluated by three evaluators) with the average distance of ping pong balls (project performance) as a dependent variable and each of



(p = 0.004) (a) Performance

(p = 0.35) (b) Original

(p = 0.49) (c) Surprising

(p = 0.25) (d) Germinal

Fig. 4. Regression analysis of the average distance and creativity versus part count.

the CPSS subscales as an independent variable. Regression lines are illustrated in the figures and p-values are shown below the figures. The average distance is not significantly associated with three subscales of Novelty (Original, Surprising, and Germinal), as indicated by p-values larger than 0.05. On the other hand, the average distance is significantly associated with subscales of Resolution and of Elaboration and Synthesis, as indicated by p-values less than 0.05, except Complex, which is moderately significant (p-value = 0.096). The average distance is only negatively associated with Complex as indicated by a negative slope of the regression line. The negative slope indicates that projects that are assessed as complex do not perform well.

Figure 4 shows a regression analysis of the average distance (project performance) and creativity (Original, Surprising, and Germinal) with respect to a part count (the number of parts). The average distance improves as the number of parts decreases, but there is no significant association between project creativity and the number of parts.

4. Risk attitudes

Students' risk attitudes toward the uncertainty of project success and failure are assessed by using the lottery in Fig. 5 and by fitting an exponential utility function in Equation (1), both of which are used to assess a decision maker's risk attitude in decision analysis [30]. Students assess probabilities p in the lottery that makes them indifferent (indicated by '~' in Fig. 5) between receiving a guaranteed intermediate grade of B, C, or D (i.e., with a probability of 1) and receiving grades A with a probability of p and F with a probability of $1 - p$.

Assigning utility of 1 to the most preferred grade,

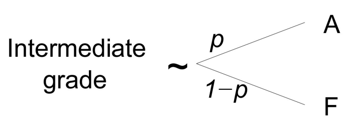


Fig. 5. Lottery.

A, and utility of 0 to the least preferred grade, F, the probability p in the lottery, which makes students indifferent between an intermediate grade and the lottery, corresponds to the utility value of the intermediate grade. For example, because indifference indicates that expected utilities are the same, utility u(G) of an intermediate grade G is equal to p, i.e.,

$$\begin{aligned} u(G) &= p \times u(A) + (1 - p) \times u(F) \\ &= p \times 1 + (1 - p) \times 0 = p. \end{aligned}$$

Table 4 summarizes the probability or utility of each grade assessed by three students.

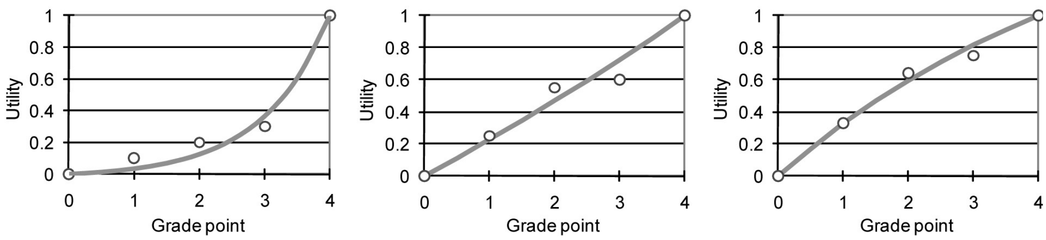
Once utility of the grades is identified, the exponential utility function in Equation (1) is fitted to five data of grade point (g) and utility (u) in Table 4. In Equation (1), the parameter r is called the risk aversion coefficient, which indicates the risk averseness of a decision maker. The larger positive value of r indicates more risk averseness, a value of 0 indicates risk neutrality, and the larger negative value indicates more risk proneness. Figure 6 illustrates the exponential utility functions of three students. According to risk aversion coefficients r, which are shown below each figure in Fig. 6, Student 1 (Project 1) is risk-seeking, Student 2 (Project 2) is approximately risk-neutral (slightly risk-seeking), and Student 3 (Project 3) is risk-averse.

$$u(g) = 1.028(1 - e^{-gr}) \tag{1}$$

Figure 7 illustrates a regression analysis of project performance and creativity (Original, Surprising, and Germinal) with respect to risk aversion coeffi-

Table 4. Preference probabilities

Grade (g)	Grade Point (g)	Probability (p) or utility (u)		
		Student 1	Student 2	Student 3
A	4	1	1	1
B	3	0.3	0.6	0.75
C	2	0.2	0.55	0.64
D	1	0.1	0.25	0.33
F	0	0	0	0

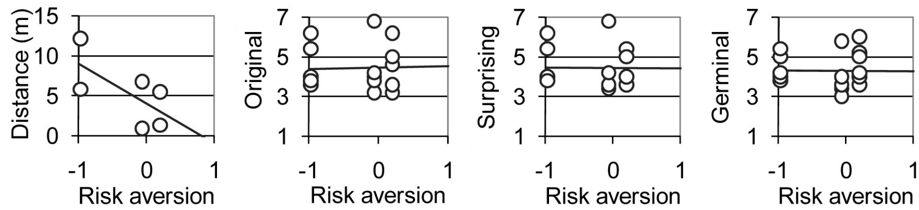


(r = –0.97) (a) Student 1

(r = –0.06) (b) Student 2

(r = 0.20) (c) Student 3

Fig. 6. Utility functions.



(p=0.003) (a) Performance

(p=0.90) (b) Original

(p=0.97) (c) Surprising

(p=0.94) (d) Germinal

Fig. 7. Regression analysis of distance and creativity versus risk aversion.

cient r. Only the average distance exhibits a significant negative association with the risk aversion coefficient, which indicates that the projects of more risk-seeking students perform better in the design projects.

5. Discussion

This paper presented a pre–post analysis of six student design projects (three projects each) before and after applying the following creativity methods: Function Analysis System Technique, mind map, analogy, and morphological analysis. The project was to create a device that launched a ping pong ball as far as possible. The project requirements were kept the same before and after applying creativity methods in order to enable a pre–post analysis. Each project was evaluated by a numeric performance score (the average distance of five ping pong balls) and qualitative scores using the revised CPSS [22].

Two of three projects (Project 2 and Project 3) embodied different design concepts after applying creativity methods. Project 1 performed best before creativity methods (Pre-1) and the same design concept was implemented after creativity methods (Post-1). The design concept of Project 2 changed after applying creativity methods because the initial design concept (Pre-2) did not perform well and because the student felt that the project performance would not improve if the same design concept were used. Project 3 before creativity methods (Pre-3) performed as well as Project 1 (Pre-1); however, a different design concept was chosen after applying creativity methods because the student felt that the design concept that used an elastic band would not further improve project performance. The CPSS *Novelty* scores (Original, Surprising, and Germinal) improved for Project 2 and Project 3 after creativity methods (Post-2 and Post-3), but only Project 2 (Post-2) improved the project performance (the average distance). Although project performance decreased, Project 3 after creativity methods (Post-3) was assessed as the most creative among all three projects based on the CPSS *Novelty* scores.

The project performance did not exhibit a significant association with the CPSS *Novelty* scores (Original, Surprising, and Germinal). On the other hand, the CPSS *Resolution* scores (Valuable, Logical, and Useful) and *Elaboration and Synthesis* scores (Organic, Elegant, Understandable, and Well-crafted) indicated significant positive associations with the project performance, except Complex of *Elaboration and Synthesis* scores. A moderately significant negative association (p-value of 0.096) between the project performance and Complex score and a significant negative association between the project performance and the part count (p-value of 0.038) indicated that a simpler design with a smaller part count tended to result in a higher project performance. This result was consistent with past studies that investigated relationships between a contest ranking and an ordinal rank of part count in design projects [23] and between a system reliability and a smaller part count [31].

A significant negative association was observed between the project performances and risk aversion coefficients, which indicated that the projects of more risk-seeking students performed better in the design projects; however, no significant association was observed between CPSS *Novelty* scores (Original, Surprising, and Germinal) and risk aversion coefficients.

To draw definite conclusions, however, further research is needed due to the following limitations. First, the number of observed students and projects is small. Larger numbers of students and projects need to be studied in order to confidently conclude the relationships among project performances, CPSS scores, part counts, and risk attitudes. For example, the project performances exhibit a significant negative association with student risk attitudes (risk aversion coefficients). This result indicates that projects perform better for more risk-seeking students. In this paper, a risk-seeking student keeps the design concept that performs well in the first project (before creativity methods) and a risk-averse student changes a design concept after creativity methods, although both students' projects perform comparably well before applying creativity methods. This may be counterintuitive and may require a further study, as more conservative (risk averse) students seem to keep a successful design concept in the first project in order to avoid risk of failure of a new design concept in the second project. If observed in a large number of students, the phenomenon observed in this study may indicate that student risk attitudes may depend on their reference points (i.e., what grade they expect to earn for the project performance). For students who *a priori* think they will earn an A, any other grades may be framed as a loss, which may cause them to be risk seeking according to the prospect theory [32, 33]. Studying relationships among project performances, CPSS scores, part counts, and risk attitudes in a larger project-based design class is a topic for future work.

Second, relationships among project performances, CPSS scores, part counts, and risk attitudes may be confounded with choice of a design concept (design strategy). In a larger team-based design project class (approximately 100 students and 25 design teams each semester) in which student teams work on more complex design projects, some design concepts tend to perform better than the other design concepts. In this paper, three projects employ different design concepts, except Project 1 and Project 2 before concept generation methods (Pre-1 and Pre-2). In order to distinguish the relationships among project performances, CPSS scores, part counts, and risk attitudes from the choice of a design concept, the relationships need to be studied for each design concept. This is a topic for future work.

Lastly, the design project studied in this paper is relatively simple. Whether or not relationships among project performances, CPSS scores, part counts, and risk attitudes are consistent in both simple and complex design projects needs to be studied as another future work.

6. Conclusions

The preliminary results of the pre–post analysis of six student design projects (three projects each) suggest that creativity methods may improve creativity but not necessarily the performance of design projects. A simpler design with a smaller part count may be necessary for a design project to perform well. If instructors wish to motivate students to embody creative ideas in functioning projects, they may need to evaluate design projects with both a creativity assessment (such as CPSS Original, Surprising, and Germinal scores) and a numerical performance assessment. Project performance alone may not be a good measure to motivate students toward a creative design project because project performance (average distance) does not exhibit a significant association with the CPSS *Novelty* scores. If project performance cannot be numerically evaluated in the concept selection stage (e.g., when choosing a device concept before prototyping), CPSS *Resolution* and *Elaboration and Synthesis* scores may be used as the means to evaluate/predict performances of design concepts as CPSS *Resolution* and *Elaboration and Synthesis* scores indicate significant positive associations with project performance, except for the Complex of *Elaboration and Synthesis*. To draw definite conclusions, however, further research is needed due to the small number of observed students and projects.

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