AC 2009-2313: AN EXAMINATION OF RAPID PROTOTYPING IN DESIGN EDUCATION

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An Examination of Rapid Prototyping in Design Education

Abstract

To evaluate the effectiveness of a rapid prototyped model, a course was examined which requires students to conceive a design and create a model or prototype demonstrating their design. Students were randomly selected from the course to be given access to the rapid prototype or to create the models (prototypes) as the class has done for more than twenty years.

The models were graded by three experts in the field using a rubric which focused on three key aspects of the model project. Those aspects included craftsmanship, design quality, and scale (proportion). The measures of craftsmanship and scale produced a large effect ($d = .82$; $d = .86$) with significant probability values ($p < .047$; $p < .043$), while the measure of design produced a small effect size ($d = .22$) with a non-significant probability value ($p < .536$) when comparing the rapid prototyped models to the traditionally built models.

Introduction

Creating physical models or prototypes has traditionally been a part of engineering and the design process. These models serve several purposes, including providing a demonstrative form of the final project and feedback for revision and improvement within the design process (Alley, 1961). In an educational setting, models and prototypes have traditionally been constructed by hand using a variety of materials in the absence of machining tools and training. This is considered a fundamental aspect of design according to the Standards of Technological Literacy set by the International Technology Education Association (ITEA, 2002), the National Academy of Engineering (NAE, 2002), and many leading engineering educators (Oaks, 2003).

In the 1980's, the manufacturing industry began developing what has evolved into rapid prototyping and three-dimensional printing technology. This technology has provided the ability for designers and engineers to create three-dimensional physical models from three-dimensional computer models. This process involves the addition of material through a variety of processes. Recently, rapid prototype technology has been incorporated into the academic curriculum of several design disciplines (Dimitrov, Schreve, & de Beer, 2006; Modeen, 2005; Tennyson & Krueger, 2001).

Many claims have been (and will be) made as to the potential for three-dimensional printing and rapid prototyping to revolutionize or enhance design education. However, no studies we indentified justify the effects as being positive, negative, or comparable when curricula containing rapid prototyping were compared with traditional methods of model construction such as carved models, shaped models out of ceramics, and models constructed from foam core or paper. There is no experimental data comparing traditional model construction techniques to rapid prototyping techniques with respect to meeting educational objectives.

Purpose

To effectively evaluate if the need and appropriateness for rapid prototyping exist within a program, the benefits and limitations of rapid prototyping must be identified and quantified when compared to current prototype construction methods. The purpose of this study was to compare traditional model building techniques to rapid prototyping in meeting design education objectives. The results are intended to provide educators data and insight into the impacts of implementing rapid prototyping technology into design curricula.

Models and prototypes serve two purposes: providing a medium for the designer to evaluate and assess a design as well as communicate the design to other individuals. This report will focus on two factors of models which lead directly to better interpersonal communication as well as formative assessments leading to design iterations. These two factors are the consistency of scale throughout the model as well as craftsmanship.

Research Question

The research question addressed in this study is given: Is the quality of the finished presentation models the same for each method? If the quality of the presentation models is different, what is the nature of the difference? Are the quality, workmanship, and ability to portray detail comparable within the two methods? If areas of the presentation model differ between the two methods, what is the nature of the difference?

Experiment

To evaluate the quality of a model/ prototype, a group of creative design students were selected from an existing course assignment. Creative design students were selected because the assessment and focus of the project were on the scale, craftsmanship, and design aspects of the model construction. The task assigned to students was the design and marketing of an original chair. Students were required to produce a presentation quality model of their design. To obtain data, three evaluators were used to minimize bias, were checked for inter-rater reliability, and instances of a possible “halo effect” (McMillian, 2001).

Evaluation

The three evaluators were all faculty at Utah State University in the Interior Design Department. The first evaluator is a professional architect with nineteen years of professional experience and sixteen years as an educator. The second evaluator has thirteen years experience as a designer and four years experience as an educator. The third evaluator has eighteen years of design experience and twelve years experience as an educator. All three evaluators have earned master’s degrees in fields of architecture or interior design. An analytic rubric was used with examples of score values to minimize subjectivity (Gall, 2003). The rubric consisted of three main categories: scale, craftsmanship, and design. Each aspect was sub-divided into five sub-categories with students scoring up to two points (three points in the case of design) in quarter point (1/4 point) increments for each subcategory. The categories and subcategories are given below:

Scale

- Internal scale consistent within model
- Consistency to human scale
- Material proportionate to full scale representation
- Model built to exact scale (1/2"=1')
- Professional Evaluator's opinion

Craftsmanship

- Material appropriate to design
- Transition, internal consistency
- Joinery
- Finish
- Professional Evaluator's opinion

Design

- Original / Creative
- Interesting
- Professional
- Design principles
- Professional Evaluator's opinion

Inter-Rater Reliability

The three evaluators were checked using a paired sample t-test for inter-rater reliability. One evaluator consistently graded students four points lower in the design category. This discrepancy was detected in the t-test. After applying a shift of four points to the first evaluator's scores, all highly non-significant results were obtained in the paired sample t-test. The shift reduced the sum of the variance in students' design scores from 136.51 to 69.83. The areas of scale and craftsmanship yielded highly non-significant p-values. Table 1 shows the paired sample t-tests for the three evaluators before and after the shift.

Table 1

Paired Sample t-Tests for Interrater Reliability

Evaluator	Mean difference	*SD*	Std. error mean	Sig. (2-tailed)
Design – before shift				
Evaluator 1 vs. Evaluator 2	-4.12	3.35	0.6	0.001
Evaluator 1 vs. Evaluator 3	-3.12	3.79	0.94	0.005
Evaluator 2 vs. Evaluator 3	1.22	3.25	0.76	0.13
Design – after shift				
Evaluator 1 vs. Evaluator 2	-.25	3.21	.56	.652
Evaluator 1 vs. Evaluator 3	.55	3.23	.78	.490
Evaluator 2 vs. Evaluator 3	1.14	3.18	.73	.135

Selection of Students

All students in the creative design course were invited to participate in the study. Students wishing to participate were given an identification number. Each student was assigned to a method of model construction using an identification number. This selection was done using a random number generator. Each student had equal probability for selection (50%) within each class section. Twenty-eight students chose to participate in the study with fourteen being assigned to a treatment group (access to rapid prototyping technology) and fourteen to a control group (hand construction methods).

Results

The research question was analyzed according to an independent sample t-test. The average of the scores of all the evaluators was used in the t-test. The three individual factors of scale, design, and craftsmanship, as well as the total of all three factors, were analyzed by the model construction technique. The mean, standard deviation, standard error of the mean, and the probability values were all reported.

Scale

The first area to be assessed in the area of rapid prototyping are the effects on scale within a model. The mean score given by the evaluators for scale compared between the rapid prototyping and the traditional hand built models shows significance ($p < .03$) in an independent sample t-test with a difference of means being 1.27 on a scale of ten. Not only was the mean greater among the rapid prototyping group, but the variance of scale was reduced as well (4.22 versus 2.00). This is shown in table 2 below.

Table 2
Comparison of Rapid Prototyping Versus Hand Construction on Scale

	Method Used	Mean	Std. Deviation	Std. Error of the Mean
Scale	Hand Construction	7.70	2.05	0.41
	Rapid Prototyping	8.97	1.41	0.37

Construction

The second area to be assessed is of rapid prototyping and the effects on construction quality within the model. The quality of craftsmanship shows to be statistically significantly ($p < .027$) better by a factor of 1.38 on a scale of ten. Similarly to scale, the variance within the craftsmanship was less with the rapid prototyping group (4.66 versus 2.38). This is shown in table 3 below.

Table 3

Comparison of Rapid Prototyping Versus Hand Construction on Craftsmanship

	Method Used	Mean	Std. Deviation	Std. Error of the Mean
Scale	Hand Construction	7.02	2.16	0.43
	Rapid Prototyping	8.40	1.55	0.41

Design

The overall mean of the students' design scores was compared for differences in rapid prototyping to traditional model construction techniques. A difference of approximately one unit out of fifteen units was exhibited with a non significant p-value ($p < .345$) in an independent sample t-test (table 4).

Table 4

Comparison of Rapid Prototyping Versus Hand Construction on Design by Mean of Evaluators

	Method Used	Mean	Std. Deviation	Std. Error of the Mean
Mean of Evaluators	Hand Construction	12.10	3.157	0.631
	Rapid Prototyping	13.09	3.009	0.825

Total Model Score

Before analyzing the total score (sum of design, scale, and craftsmanship) for the project, it was noted that mean scores of rapid prototyping projects were higher in all three areas than mean scores of hand built projects. As would be expected from the data above, the mean value of the total score was higher (3.85 units out of a total of 35) and yielded a slightly non-significant p-value ($p < .081$) on an independent sample t-test (table 5).

Table 5

Comparison of Rapid Prototyping Versus Hand Construction on Total Score by Mean of Evaluators

	Method Used	Mean	Std. Deviation	Std. Error of the Mean
Mean of Evaluators	Hand Construction	26.61	6.770	1.354
	Rapid Prototyping	30.46	5.742	1.534

Summary

In all categories, the mean score of students using rapid prototyping was greater than the mean score of students using traditional hand techniques. The greatest areas of difference were found in scale and craftsmanship. This was expected in the literature (Bohn, 1997; Flowers, 2002; Gibson, Kvan, & Ming, 2002; Iwamoto, 2004) and was expected in the study. The large effect size of the difference in scale ($d = .68$) and craftsmanship ($d = .70$) carried over into the total score ($d = .60$).

A difference was found in design, but lacks statistical significance. A test of effect size ($d = .32$) yields a small to medium effect size which would be too small to detect significance in the sample size. A sample size greater than 50 per group would be required to give the power necessary to avoid a type II error with a small effect size (Moore, 2006). The data suggests that further exploration is needed to identify if rapid prototyping does have a small to medium effect as indicated. This area was not addressed within the literature. Transferability of this data is limited to design projects in which the model/ prototype quality is important and students have limited access to appropriate machining and construction equipment. The data also suggests rapid prototyping may have an effect on student design structures because forms are no longer limited to linear designs.

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