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Measuring Creativity in Die Products for Technological Education

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Abstract**—**Creative design requires new approaches to assessment in vocational and technological education. To date, there has been little discussion on instruments used to evaluate dies produced by students in vocational and technological education. Developing a generic instrument has been very difficult due to the diversity of creative domains, the specificity of content, and the subjectivity involved in judgment. This paper presents an instrument for measuring the creativity in the design of products by expanding the Consensual Assessment Technique (CAT). The content-based scale was evaluated for content validity by 5 experts. The scale comprises 5 criteria: originality; practicability; precision; aesthetics; and exchangeability. Nine experts were invited to evaluate the dies produced by 38 college students who enrolled in a Product Design and Development course. To further explore the degree of rater agreement, inter-rater reliability was calculated for each dimension using Kendall's coefficient of concordance test. The inter-judge reliability scores achieved significance, with coefficients ranging from 0.53 to 0.71.

Keywords**—**Design education, die creative product, vocational and technological education, Consensual Assessment Technique (CAT).

I. Introduction

PRODUCT design and manufacturing is at the core of industrialization and commercialization. Design is defined as the process of transforming an abstract function into concrete products. Manufacturing involves the use of machines, tools, and labor to produce goods for use or sale. Manufacturers have realized that improving production quality, accelerating production processes, and reducing costs are essential to survival in the competitive global market [1]. A wide range of products are made from dies and some products comprise thousands of components formed from dies [2]. Die making represents a critical element of the manufacturing sector.

Slack [3] claimed that product design is "a generic term for the creation of an object that originates from design ideas –in the form of drawings, sketches, prototypes or models – through a process of design that can extend into object production, logistics, and marketing". Creativity is a basic element of product design. In 2002, the Taiwanese Ministry of Education initiated a series of projects aimed at making Taiwan a Republic of Creativity (ROC). According to the White Paper of Creative Education promoted by the Advisory Office of Ministry of Education [4], the hope of ROC was to make Taiwan a place where creativity is "indispensable to everyone's life and in which the preservation of creative capital will be maintained through knowledge management" [5].

Numerous researchers have fueled the controversy as to whether the source of creativity is domain-general or domain-specific. Creativity is specific or general depending on the methods [6, 7]. According to the domain-general view, creativity is a general skill or characteristic that can be applied to a wide variety of situations (i.e., research focuses on the creativity of individuals). By contrast, the domain-specific view of creativity is that different domains require different kinds of creative ability (i.e., research focuses on the creativity of products) [8, 9]. Unfortunately, understanding domain-generality vs. specificity in creativity is difficult because the lack of a consensual definition of the concept of a domain makes it impossible to gain a clear sense of exactly what domain-specificity refers to [10].

In this rapidly changing era, creativity and technology are closely related. The instruction of creativity in technology education focuses on engaging students through the development of new products to solve technological problems, thereby becoming familiar with engineering as well as technical knowledge and skills [11-13]. Determining how to promote creativity among students is an important topic in vocational and technological education; however, evaluating creativity is problematic. Developing a measurement for judging dies is crucial. In recent years, considerable efforts have gone into developing the means by which to measure the creativity in product innovation for specific topics. For example, Horng [14] applied grounded theory to develop the Creative Culinary Product Criteria Matrix for analyzing the properties of innovative culinary products. Hsu et al. [15] developed the Technical Creativity Tests of Electronic and Electric Cluster for high schools. Horng and Lin [16] developed the Scale for Evaluating Creative Culinary Products and adopted the Consensual Assessment Technique (CAT) to establish the credibility of the scale.

Over the past several years, there has been a great deal of product creativity and impressive empirical investigations in this field. The development of a scale to evaluate creativity in the production of dies is limited, and using such an instrument out of context can be misleading. A more authentic and fair method of assessment could help instructors to evaluate technical implementation, and comment on the value of the product to encourage students to engage in creative thinking.

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II. Review of the Relevant Literature

A. Definition of Creativity

Creativity can be considered either sophisticated or elusive due to differences in research orientation. This dichotomy has led to a lack of consensus regarding definitions and measurements of creativity. Lack of a clear definition leads to erroneous assumptions and misguided concepts. According to [17], a number of researchers have investigated the definition of creativity as an intellectual construct. Furnham and Bachtiar [18] reported that there are more than 60 definitions of creativity without a single authority or consensus on its definition, or operational measure. Nonetheless, a commonly accepted definition of creativity is stated as the ability or power to bring into existence, to produce through imaginative skill, the concept of producing of an idea or product that is both novel and utilitarian [6, 19-22]. As Sawyer [23] explains, creativity is "the emergence of something novel and appropriate, from a person, a group, or a society" (p. 34). Ormrod [24] claimed that creativity is a form of transfer, because it involves applying previously learned knowledge or skills to a new situation to yield an appropriately productive result.

B. Creative Product

A number of definitions of creativity focus on products. Ghiselin (1963) stressed that creative products are an indication of new meaning, new insight, or aesthetic realization. The creation of products can be considered the production of novel and appropriate ideas and products [25-28]. Creativity in products is viewed as the practical application of a novel solution to a problem[29].

Teachers use assessment criteria to evaluate the products their students produce. The most widely adopted measurement of creativity in product design is the Consensual Assessment Technique (CAT) developed by Amabile [30], and extended by others [8, 31-33], in which groups of expert judges rate original products according to subjective criteria. Because the validity of CAT is not tied to a particular theory of creativity, it also has been called the gold standard of creativity assessment [34]. To facilitate the empirical study of assessing creativity in product design, Amabile [25, 35] stated that "a product or idea is creative to the extent that expert judges independently agree that it is creative". The experts are the people familiar with the domain in question. Therefore, creativity can be determined according to the judgment of multiple independent experts or can be rated as the products of the person's ideas (objects). From the above description, Amabile defines creativity from the viewpoint of production, believing that a creative product must be novel and appropriate, useful, or valuable. Dineen et al. [36] point out that "creativity requires both divergent/productive thinking to ensure novelty and convergent/reproductive thinking to ensure appropriateness". Therefore, creative products can be considered the production of novel and appropriate ideas and products.

C. Criteria of Creativity in the Design of Products

Amabile et al. [35] used their early studies to assemble criteria for creativity-related skills and domain-related skills, to validate the componential model of creativity and evidence for rater consistency. Artistic creativity was given 23 criteria, such as overall creativity, novelty, aesthetic appeal, symmetry, and expression. Language creativity was assigned 14 criteria, such as overall creativity, novelty, emotionality, grammar, and rhythm. Amabile determined that creativity and technical goodness influence creative in the design of products and achieved an internal consistency in those studies consistently above 0.70 and often exceeding 0.90 [37]. Creativity and technical goodness also demonstrated high factor loadings showing that the criteria of technical goodness can be used to interpret both the creative and technical features of a product. Practice-based research led Amabile et al. to use two dimensions (creativity and technical goodness) in CAT research [38-40]. The definitions of two dimensions were as follows: Creativity: Use personal definitions to evaluate the creativity in the design of the product; Technical goodness: The product shows good technical skill.

Most studies have applied the consensual assessment technique to measure creativity in the design of products [32, 33, 41-44]. For example, Garaigordobil [45] employed plays to stimulate graphic–figural creativity among 86 children aged 10 and 11 years in quasi experimental pretest intervention–posttest with control group method. Graphic–figural creativity was evaluated based on the judgment of two artists who independently assessed the creativity of the products using agreed upon criteria. The criterion of creativity included the following: (1) novelty; (2) insightful associations; (3) sense of humor; (4) fantasy capable of transcending reality; (5) unusual perspective; (6) transformation; (7) expressive strength. Priest (2001) evaluated creativity in the compositions of 54 students (non-music majors) enrolled in classes dealing with music fundamentals. In addition to a five-point scale to measure their compositional creativity, the evaluation included three criteria, such as melodic interest, rhythmic interest, and personal preference.

The research [46] proposed the creative product analysis model (CPAM), which is made up of three dimensions (novelty, resolution, and style) and broken down into nine categories developed from the creative product semantic scale (CPSS), an instrument used to reveal creativity in products. Novelty includes new materials, new processes, new concepts, and other elements of new products or ideas. Novelty is reflected in originality and surprise. Resolution refers to how well the product accomplishes what it is supposed to do. It includes four categories: logic, usefulness, value, and understandability. Elaboration and synthesis refer to the progression of the initial design to increase its simplicity and refinement. It includes three categories: organic, well-crafted, and elegant. Although most studies have applied the CAT to measure creativity, other studies have developed other criteria for their subjects. Overall, in previous research, most of the criteria for creativity in the design of products can be summarized as the following: creativity, technical goodness, novelty, originality, appropriateness, and aesthetic appeal [32, 37, 45, 47].

III. Methodology

A. Step one: Producing Dies for Evaluation

1. Participants

This study recruited thirty-eight college students enrolled in a Product Design and Development course. The participants were 33 male and 5 female aged between 20 and 22 years of age.

2. Manufacture Procedure

In the Product Design and Development course, the instructor asked students to design a die and provide the specifications of the workpiece (e.g., width, height and depth). The study was conducted in a mechanical facility in which a CNC milling machines and conventional milling machines were employed as the primary tools. The dies were produced from medium carbon steel (S45C). Participants were given five hours to produce dies (stamping die and plastic injection). Following completion of the dies, each of the students was identified only by a number. All products were prepared to be rated, as shown in Figs. 1 and 2.

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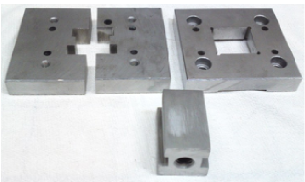

Fig. 1 Stamping die

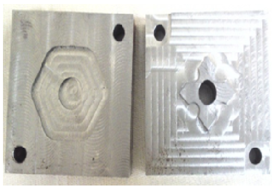

Fig. 2 Plastic injection die

B. Step two: Rating the Die Product

1. Rating procedure

Each die had to be consistent with CAT methodology. The instrument was designed according to the tenets of the precision machinery manufacturing course, combined with (CSDS) [48, 49] and car product creativity [50], to assess creativity in the production of dies. The experts assigned scores from 1 to 5 points according to each of these criteria, indicating the degree to which the product was considered creative, relative to the dies produced by other students.

2. Raters

Nine expert raters in the field of die making were invited to participate as judges in this study. Each of the judges had considerable experience in precision machining or machine-driven industries. The experts initially assessed the creativity of all of the dies using a 5-point scale in randomly assigned order to prevent order effects. Second, expert raters assessed the dies individually and without any instructions from the researcher. The experts did not meet or talk about their ratings with one another until after all the ratings had been submitted.

IV. Results

The content-based instrument was evaluated for content validity by a panel of experts. With input from faculty, 5 experts in the fields of precision machining or machine-driven industries were invited to participate in this process. Drafts of the instrument were emailed to each of the experts for evaluation. Five experts indicated that the measurement was well aligned with the content of assessing creativity in the production of dies. The instrument was revised according to expert recommendations.

To further explore the degree of rater agreement, inter-rater reliability was calculated for each dimension using Kendall's coefficient of concordance test. It is a test of correlation employed for three or more sets of ranks, which allows a researcher to evaluate the degree of agreement between m sets of ranks for n participants. To analyze the rankings, the Kendall coefficient indicates the degree to which the judges agree in their assignment of rank. The Kendall coefficient W is based on the deviation in the total of each ranking [51].

As shown in Table I, medium and significant reliability was found among the nine judges for each of the dimensions. Significant reliability coefficients ranged from .529 to .71.

TABLE I
Results for the Kendall's Coefficient of Concordance

Die criteria	Kendall *W*
originality	.529*
practicability	.710*
precision	.695*
aesthetics	.689*
exchangeability	.548*

*p<.05

V. Conclusion

Results provide evidence to support the use of the CAT in the assessment of creativity in the design of dies. Inter-judge reliability scores achieved significance, with coefficients ranging from 0.529 to 0.71 for each of the 5 dimensions rated. Hopefully these findings will encourage college instructors to include instruction in creativity, giving them confidence to proceed with the assessment and development of creativity in die production. This instrument emphasizes the importance of creativity in die production, as a learning goal in the future. This instrument is also available for training programs in the die making industry and will help to strengthen the creativity of inventors. This instrument could provide a standard with which to evaluate the performance of inventors.

VI. Directions for Future Research

Product innovation represents the key to victory in the manufacturing industry. Design and creativity are closely related; however, psychological inertia pushes us toward old modes of thought when solving problems. Many inventors use trial and error, but this is a highly inefficient approach. If inventors or designers could be provided a systematized means of thinking, they could create better products in a shorter time. Most people adopt past experience to deal with current problems, but this mode of thought is very limited and difficult to escape. Therefore, a problem-solving strategy known as

Teoriya Resheniya Izobretatelskikh Zadatch (TRIZ) comprising 39 contradiction and 40 principles, has been proposed to enable designers to improve their thinking processes. It represents a powerful alternative to trial and error [52, 53]. Future research could concentrate on applying the matrix and the statistical technique of TRIZ to develop a design process for the production of dies.

A second suggestion for future research would be to study data in confirmatory factor analysis to demonstrate the scale's reliability and validity, and to ensure that the scale is a stable measurement promoting the production of novel die-cast products and improve education in mechanical design. Furthermore, in design education, project-based learning has been a mainstay of instruction at most universities. However, Christiaans and Venselaar [54] question the effectiveness of this approach. Therefore, the issue of project-based learning is an intriguing one, which could be usefully explored in further research.

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