AC 2008-53: SORTING OUT CREATIVITY IN DESIGN ASSESSMENT

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Sorting Out "Creativity" in Design Assessment

Abstract

This paper describes the early development of a practical framework for the assessment of products of design that is aimed at resolving some of the confusion surrounding "creativity" within that field. In particular, key concepts from problem solving theory are used to distinguish between the creative level and creative style of a product, and a new assessment instrument for the creative style of a product is introduced. The instrument is applied to a selection of fastener products to illustrate its use and explore its benefits and limitations.

Introduction

Whether it takes place in industry or in the classroom, assessing the products of design is a challenging task that involves the evaluation of many interrelated factors. In addition to familiar criteria with fairly straightforward metrics (e.g., technical correctness, quality of performance, environmental impact), designs are often evaluated – both formally and informally – in terms of less concrete and generally ill-defined criteria like "creativity" or "innovativeness". We say that these latter criteria are ill-defined because there is little consensus in the literature (even among experts) about the *general* definition of creativity, much less how creativity should be understood and interpreted when applied to specific domains like engineering design[12, 19]. The word "innovation" is currently suffering from a similar fate, with equally confusing results[15].

In this paper, we will explore a framework for assessing products of design that helps alleviate this confusion by drawing a sharp distinction between the creative level and the creative style of a product. These two orthogonal (i.e., independent) dimensions have their roots in problem solving theory, where individual problem solvers are characterized by their diverse creative (cognitive) levels and creative (cognitive) styles[11, 12, 16]. In the context of the individual, creative level refers to a person's capacity for problem solving, while creative style refers to the preferred manner in which an individual solves problems[12].

Level and style can also be used to describe the outcomes of problem solving – i.e., to describe products. In this context, the creative level of a product refers to its degree of technical advancement and/or complexity, while the creative style of a product refers to its conceptual and practical relationship to the current technical "paradigm" or state-of-the-art. We will discuss in detail the distinction between the creative level and the creative style of a product and provide examples of features that characterize both.

In addition, we will present a new creative style assessment instrument for products of design. This assessment is based on six factors: the type of technical change represented by the product; the acceptability of the product; the technical feasibility of the product; the efficiency of the product; methods used in the product's development and manufacture; and the knowledge context for the product[7], all of which we will describe in detail. We will also demonstrate use of the instrument through its application to a sequence of fastener products developed between 1800 and the present (e.g., garment, slide, and "hookless" fasteners; various zipper designs;

Velcro®; and Ziploc® bags). Finally, we will discuss the benefits and limitations of both the general framework for product assessment described above and the new assessment instrument, identifying directions for future research and practical application.

Ill-Defined Criteria: Confusion about Creativity

The state of confusion surrounding the definition of creativity is a long-standing one. As early as 1960, scholars had identified over 50 different definitions for creativity in the extant literature, and the situation had not improved two decades later when other researchers revisited the task[19]. The situation is equally problematic today, as disagreements about the definition of novelty and the role it plays in creativity are further compounded with controversy over the relationship between creativity and divergent thinking[12, 19]. Other factors, such as intrinsic task involvement, leadership traits, and perception have also been proposed as important in the understanding of creativity, but few attempts have been made to synthesize or rigorously validate these views[19].

As Parkhurst notes, this lack of consensus has made it difficult for educators to identify, nurture, and encourage creativity in the behavior of students, since one cannot readily measure or impact what one has not clearly defined[19]. This poses a dilemma in engineering design, where students' design projects are often assessed in terms of their "creativity" and/or "innovativeness". The meaning of these terms is rarely (one might even venture to say "if ever") defined ahead of time, leading us to wonder: exactly what expectations are the students being asked to meet with regard to creativity, and what rubric(s) are their instructors using to assess them? Without a better framework for defining creativity (in design and elsewhere), instructors cannot evaluate their students accurately and objectively or guide them towards improved performance.

Sorting Things Out: Problem Solving and the Distinction between Level and Style

To help resolve this dilemma, we turn to Kirton's Adaption-Innovation (A-I) theory[12], a well-established branch of problem solving theory that offers rigorous definitions and clear distinctions between concepts and terms related to creativity. A-I theory has been validated in practice for over 30 years, with more than 300 scholarly articles and 90 theses devoted to its exposition and application in many (and diverse) fields. In this section, we will outline some of the key features of A-I theory as it applies to individuals (i.e., problem solvers), extending these concepts to the outcomes of problem solving (i.e., products) in the following section.

In accord with Guilford and others[8, 12, 19, 22], A-I theory is based on the assumption that all human beings are creative and solve problems (indeed, the brain cannot distinguish between the two), but we do so with different capacities and in different ways. Formally, this cognitive diversity may be described in terms of *cognitive* (or *creative*) *style*, which describes the stable, characteristic, and preferred manner in which an individual responds to and seeks to bring about change (including the solution of problems), and *cognitive* (or *creative*) *level*, which refers to an individual's inherent potential capacity (such as intelligence) or manifest capacity (such as learned competencies)[12]. Messick contrasted the properties of cognitive styles and intellectual abilities (i.e., cognitive level), noting that "abilities are seen as unipolar, whereas cognitive styles are typically conceived to be bipolar"[16]. That is, abilities range from none to a large amount, while cognitive styles range from one extreme to a contrasting extreme (see Figure 1).

Both cognitive level and cognitive style have multiple dimensions, each of which is measured using an appropriate psychometric instrument. As noted above, for example, *cognitive level* can be measured in terms of potential capacity through intelligence tests and/or talent evaluations, while manifest capacity may be assessed in terms of (e.g.) skills, knowledge, and/or expertise. One of the most familiar dimensions of *cognitive style* may be Introversion-Extraversion, which is often (although not the most accurately) measured using the Myers-Briggs Type Indicator (MBTI®)[17]; Active-Reflective learning style (measured via the Learning Style Questionnaire[9]) is another example. Kirton and others have demonstrated the independence of cognitive style and cognitive level through numerous studies[12]; thus, information about an individual's cognitive level (capacity) provides no information about that person's cognitive style (preferred approach), and vice versa.

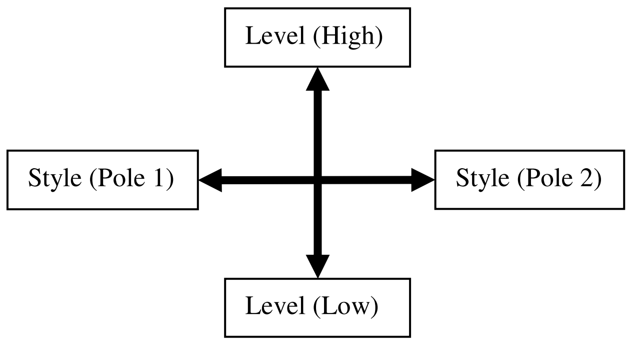

Figure 1: Independence of creative (cognitive) level and creative (cognitive) style

For the purposes of sorting out creativity in design assessment, we will rely on the dimension of cognitive style known as Adaption-Innovation, which (when applied to individuals) is measured using Kirton's Adaption-Innovation inventory (or KAI®)[12]. As measured by KAI, cognitive style lies on a continuum that ranges from strong Adaption on one end to strong Innovation on the other (see descriptions below). For large general populations (across cultures), the distribution of KAI scores forms a normal curve within the range (32 – 160), with an observed mean around 95 (see Figure 2)[12].

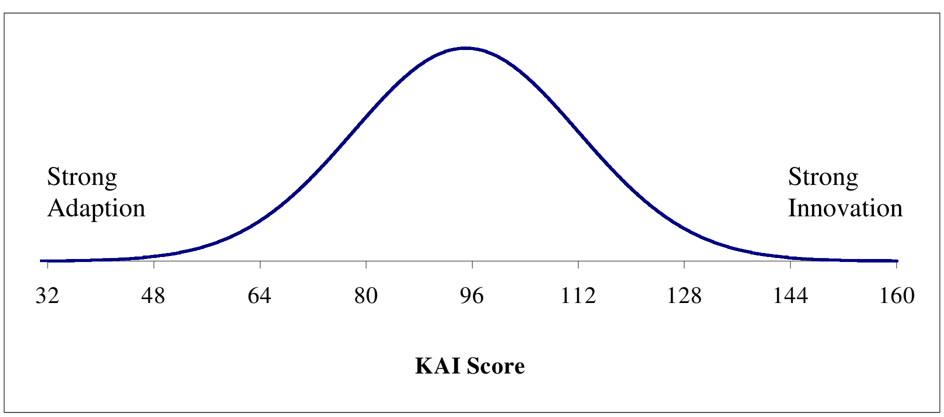

Figure 2: Adaption-Innovation style continuum and typical distribution for general population

The key distinction to differences between adaptive and innovative (as defined by Kirton) individuals is related to their preferred manner of handling structure in problem solving. Individuals who are more adaptive prefer to operate with *more* structure, and with more of this structure consensually agreed. More innovative individuals prefer to solve problems using *less* structure, and they are less concerned with consensus concerning that structure. One way of summarizing this basic difference is to say that the more adaptive prefer to solve problems *using* "the rules", while the more innovative tend to solve problems *in spite of* them[10, 11, 12].

These differences in cognitive style produce distinctive patterns of behavior (although an individual can behave in ways that are not preferred; this is called *coping behavior*)[12]. More adaptive problem solvers generally accept problems as they have been defined, along with any agreed-upon constraints. In collecting data, they tend to be more meticulous and exhaustive than their more innovative counterparts, favoring information and perspectives that are closely related to the original problem structure. When generating ideas, adaptive individuals prefer to generate a few novel solutions that are relevant, readily acceptable, and aimed at improvements on the current system. In essence, the more adaptive problem solver strives to do things "better"[10].

More innovative problem solvers, on the other hand, often reject the original, generally accepted definition of a problem and redefine it. In collecting data, they tend to look outside the original problem structure for different perspectives, which they bring into the solution process in ways that may seem disruptive to their more adaptive counterparts. When generating ideas, innovative individuals prefer to produce numerous novel ideas, some of which may not appear relevant to the problem and/or may be more difficult to implement as part of the current system. In short, they seek ways to do things "differently"[10].

Because of these preferences, adaptors and innovators view technical domains and their respective boundaries in different ways. As illustrated in Figure 3a, adaptive individuals tend to view the definitions of or constraints associated with a particular technical domain as solid and relatively fixed. Thus, we find that adaptors tend to design products that remain within or closely connected to the current domain of interest, since they are likely to search that domain thoroughly for solutions before looking elsewhere[10, 12]. Such products may be perceived as "evolutionary", representing sound, incremental improvements to existing technologies that are readily recognized as relevant to the current problem or need.

Innovative individuals, in contrast, tend to view the boundaries of a technical domain as flexible or uncertain, if they recognize their existence at all (see Figure 3b). Thus, we find that innovators tend to design products that stretch the boundaries of a particular technical domain, or even span several domains[10]. Such products may be perceived as "revolutionary", bringing together diverse areas of technology and combining them in unexpected ways. But there is another possible result of the innovator's fuzzy view of domain boundaries: since they are unsure of where the boundaries lie, they may be just as likely to design products that lie within them as outside them, although those products are unlikely to fall too close to the domain's core[10, 12]. It is these general trends that we will use as the foundation for our assessment of the products of design in terms of creative style.

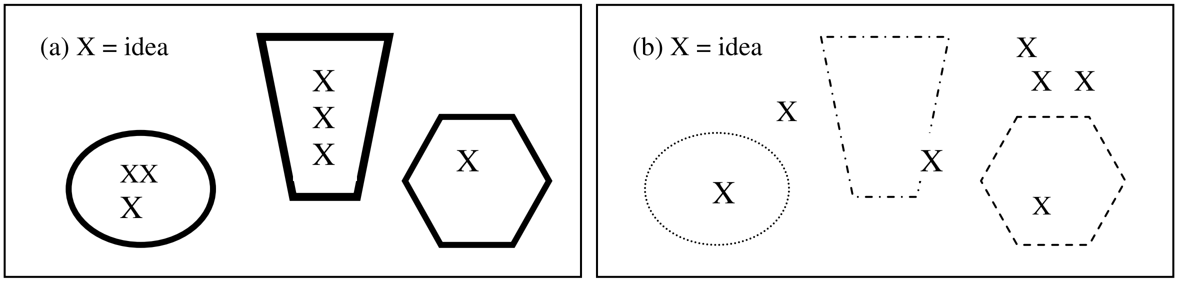

Figure 3: Perspectives on technical domains and boundaries - (a) adaptive; (b) innovative

Level and Style Applied to Products of Design

We are not the first to suggest that products can be assessed in terms of their "creativity"; in particular, Rhodes[22], MacKinnon[13, 14] and Amabile[1] all argue that an analysis of products is an appropriate starting point in the study of creative behavior. The main difficulty lies, once again, in the fact that the current definitions for creativity being applied to products are often indeterminate, and hence, no matter how rigorous the assessment *process* may be, any conclusions drawn are limited in their value. For example, definitions of what makes a product "creative" often contain references to novelty and usefulness[1, 5, 14], without sufficiently tight definitions for either characteristic, while some researchers also include criteria related to aesthetic quality[13, 25].

Given the general principles of Adaption-Innovation theory described above (i.e., the distinction between and independence of creative level and creative style), our aim here is to extend the notion of independent level and style continua to products and to propose a framework and process for assessing a product's creative style. Specifically, in expanding the notion of *creative level* to include products, we propose that those features or characteristics of the product that are related to its degree of technical advancement, complexity, and/or quality of performance be considered – that is, features related to its functional "capacity" or "facility" (see Table 1). In extending the concept of *creative style* to products, we will consider the relationship of the product to the current technical paradigm (i.e., the state-of-the-art), as well as its impact on related systems (including those required to manufacture it) and the timeframe required for the product's acceptance and return on investment (i.e., its "efficiency").

With these broad guidelines and examples in place, it is interesting now to consider some product assessment techniques found in the literature and their relationship to level and style. As a starting point, Christensen's definitions of sustaining and disruptive technologies relate to a product's "performance" (i.e., acceptance) in the marketplace[6]. Specifically, Christensen's "sustaining technologies" improve the performance of established products (e.g., make existing products better, sell for higher margins) along the dimensions historically valued by mainstream customers. In contrast, his "disruptive technologies" do not perform well initially in mainstream markets; eventually, they do manage to lower costs and achieve simplicity, but immediate benefits are not usually seen. These descriptions correspond quite well with Kirton's definitions of more adaptive and more innovative ideas/solutions, respectively, although Christensen does not make use of the entire spectrum of styles in his model.

Table 1. Product features related to level and style

Creative Level	*Creative Style*
Technical advancement: - Physical/mathematical principles involved (basic vs. advanced) - Depth of knowledge required	Relationship to current technical paradigm: - Incremental vs. radical change - Amount of consensus among practitioners in the field
Complexity: - Number and nature of components - Number and nature of connections between components	Impact on related systems: - Manufacturing (e.g., need to retool) - Number and type of new markets served
Performance quality: - Accuracy, precision - Repeatability - Reliability	Benefits and acceptance: - Efficiency (immediate vs. eventual) - Acceptance (narrow vs. wide)

Besemer & Treffinger[4] performed a formalized study of "creative products" with their review and identification of 125 criteria used in different product assessments. They synthesized these criteria into a model for studying the attributes of products called the Creative Product Analysis Matrix (CPAM), which includes three general dimensions: *novelty*, *resolution*, and *elaboration and synthesis*. In their model, *novelty* refers to "the extent of newness of the product", under which descriptors like "germinal", "original", and "transformational"[4] are used. While this dimension seems to correspond more to style than level, it shows a distinct "innovation bias"; that is, their definition of novelty is skewed toward one end of the A-I style continuum. The second dimension of CPAM, *resolution*, is related to "the degree to which the product fits or meets the needs of the problematic situation"[4]. This dimension refers to the "appropriateness" of the product for resolving the problem at hand, a quality which would certainly involve both style and level, making it too general and confounded for our use here. Finally, *elaboration and synthesis* is defined as "the degree to which the product combines unlike elements into a refined, developed, coherent whole statement or unit"[4]. This third dimension seems more closely related to style than level, but again, an "innovation bias" is implied in its definition.

Based on Besemer & Treffinger's theoretical model, as well as consensual techniques similar to Amabile's CAT[1], the Creative Product Semantic Scale (CPSS) was developed by Besemer & O'Quin to assess the creativity of products[2, 3, 18]. Applications of the CPSS include industrial and educational settings, but the instrument is not currently available for general use. In addition, Puccio, Treffinger & Talbot[21] made an explicit investigation of the relationship between individuals' perceptions of the characteristics of their products and their respective cognitive styles as measured by KAI. As might be expected, adaptive individuals described their products as logical and well-crafted, while innovative individuals described their products as original and transformational.

Another design approach that provides some interesting insight into product assessment is TRIZ, or the "theory of inventive problem solving"[23, 24]. TRIZ suggests that different types (or "levels") of products exist, with fundamental differences linked to the technical knowledge required for the development and manufacture of that product. Specifically, a "Level 1" product represents a simple improvement of a technical system that requires knowledge within a related trade, while a "Level 2" product requires the resolution of a technical contradiction and knowledge from different areas within a related industry. "Level 3" products require the resolution of physical contradictions and knowledge from different industries, while "Level 4" products involve the development of a new technology, including breakthrough solutions that require knowledge from different fields of science. Finally, a "Level 5" product results from the discovery of a completely new phenomenon[23, 24]. These categories seem more closely related to style than level (using Kirton's terminology), despite their labels.

A Creative Style Assessment for Products of Design and Invention

Synthesizing insights from the work described above with Kirton's problem solving framework, we developed a prototype creative style assessment instrument for products of design[7]. The new instrument utilizes a continuum of product styles that range from highly adaptive to highly innovative, with six factors assessed for each product: type of technical change, acceptability, feasibility, efficiency, method, and knowledge context. Table 2 shows the general layout of the instrument and these six factors, which we will now describe in more detail. Note that the individual factor continua have been segmented to provide evaluation "milestones" in this prototype version of the instrument; this segmentation may be eliminated in future revisions.

Table 2. Creative Style Assessment for Products: General Layout

	More Adaptive <-----				-----> More Innovative
FACTORS	**1**	**2**	**3**	**4**	**5**
Type of Technical Change	...	...	...	...	...
Acceptability	...	...	...	...	...
Feasibility	...	...	...	...	...
Efficiency	...	...	...	...	...
Method	...	...	...	...	...
Knowledge Context	...	...	...	...	...
TOTALS (by column)	...	...	...	...	...
MEAN SCORE	<--------------------				-------------------->

Type of Technical Change: This first factor is used to evaluate the technical change represented by the new product when compared to previous products; i.e., in terms of its technical content, does the product represent a more adaptive change or a more innovative change with respect to the state-of-the art? Here, we consider the structure, use, and purpose of the product, where changes in these elements can range from incremental revisions (more adaptive) to radical modifications (more innovative). Table 3 shows the detailed descriptions provided for the five "milestone" segments within this factor.

Table 3. Type of Technical Change (Factor 1)

	More Adaptive				More Innovative
Type of Technical Change	Incremental revision, refinement, or modification of an existing product requiring little or no structural change to that product.	Incremental to moderate revision, refinement, or modification of an existing product involving small to moderate structural change to that product.	Moderate revision or modification of an existing system involving not only a moderate structural change to the system, but also at least one new use for that system.	Moderate to significant revision or modification of an existing system that involves a major structural change to the system and may allow that system to be used for many purposes.	Replacement of most or all of an existing system, resulting in a solution that is radically different from the original system in terms of both structure and usage.
	Incremental, sustaining, evolutionary, "better"	Small change of an earlier prototype involving the enhancement of particular feature(s).	Introduction of an entirely new sub-system.	Introduction of many new sub-systems.	Tangential, disruptive, revolutionary, "different".

Acceptability: This second factor takes into account how readily and widely accepted the new product is, as we take note of its placement in relation to the state-of-the-art (current paradigm). Products that are seen to be immediately relevant to the problem at hand (more adaptive) are generally accepted more readily (whether or not one thinks the product is the "best" solution), while products that "break the norm" (more innovative) require more time for acceptance due to the larger "package" of change (i.e., a new paradigm and a solution within it) that must be sold[12]. The detailed segments for this factor are shown in Table 4.

Table 4. Acceptability (Factor 2)

	More Adaptive				More Innovative
Acceptability	Solution falls within the accepted frame of reference, is immediately seen as relevant to the current problem, and fits within the trade's current paradigm.	Solution still seems relevant to the current problem, but may approach the boundaries of the trade's current paradigm.	Solution lies outside the trade's paradigm of accepted ideas and principles.	Solution lies outside the industry's paradigm of accepted ideas and principles.	Solution lies outside society's current paradigm and therefore seems to 'break the norm' and oppose most consensus views.
	Safe, sound, logical.				Startling, shocking, risky.

Feasibility: This factor takes into account how feasible the product is in terms of the current technological environment, the number of personnel involved in implementation, and the cost and time involved to arrive at a successful solution. Here, adaptive products generally have higher feasibility, since they tend to involve refinements of the current system (as opposed to its replacement). In contrast, innovative products may involve radical shifts in standard practices, which are more difficult to bring about and take longer to stabilize. Table 5 shows the detailed segments for the feasibility factor.

Table 5. Feasibility (Factor 3)

Feasibility	More Adaptive				More Innovative
	Easy to implement, requiring the work of only a few personnel.	Somewhat easy to implement, requiring a small team working together.	Moderately easy to implement, requiring a large team working together.	Somewhat difficult to implement, requiring the work and effort of an entire department.	Very difficult to implement, requiring the work of an entire company.
	Requires little to no cost to implement.	Requires minimal cost to implement.	Requires moderate cost to implement.	Requires moderately large cost to implement.	Requires large cost to implement.
	Takes one attempt to arrive at successful solution.	Takes only a few attempts to arrive at successful solution.	Takes a few dozen attempts to arrive at successful solution.	Takes a few hundred attempts to arrive at successful solution.	Takes a few thousand attempts to arrive at successful solution.

Efficiency: The efficiency factor takes into account the "directness" of the solution in relation to the problem at hand, as well as its risks and overall benefits. For example, the product may address the given need directly and immediately (more adaptive), or the solution may address a different need altogether (more innovative). Another aspect of efficiency is how soon the benefits of the product are seen. With the introduction of the new product, there may be immediate improvements (more adaptive), or the product may not perform well initially, and benefits may only be seen in the long term (more innovative). Table 6 illustrates the details of the efficiency factor.

Table 6. Efficiency (Factor 4)

Efficiency	More Adaptive				More Innovative
	Solution addresses original problem directly.	Solution addresses original problem after slight refinement.	Solution addresses original problem after moderate refinement.	Solution addresses original problem after considerable refinement.	Solution addresses problems other than the original problem.
	Early resolution to the problem with immediate increased efficiency.	Early resolution to the problem with eventual increased efficiency.	Early resolution to the problem with long term increase in efficiency.	Eventual resolution to the problem with long term increase in efficiency.	Does not initially perform well; overall improvement over very long term.
	Predictable and expected outcomes that are likely to work and be immediately functional.				Unexpected and unpredictable outcomes.

Method: The method factor considers the way in which the product was created, including which methods were used, which historical data and rules were incorporated, and which tools were necessary when designing and manufacturing the product. In this case, the more one makes use of existing processes, tooling, and manufacturing systems, the more adaptive the product is considered to be, while products that require extensive retooling and the development of new processes and equipment are more innovative. The details of this factor are illustrated in Table 7.

Table 7. Method (Factor 5)

	More Adaptive				More Innovative
Method	Solved using methods well-known with the specialty or company. Requires no new tooling, processes, hardware, software, etc.	Application of uncommon methods from the same engineering field with some additional knowledge from the designer's specialization.	Makes use of methods from other engineering fields.	Utilizes methods from other disciplines (sometimes far from the major engineering field or industry).	Utilizes methods from various sources, disciplines, studies, and areas of interest. Requires extensive use of new tooling, processes, hardware, software, etc.

Knowledge Context: With this final factor, the domains of knowledge and experience used when designing and manufacturing the product are considered. The more diverse the areas of knowledge and experience required, and the more widely spread and/or tangential those areas are with respect to the knowledge base traditionally associated with the product, the more innovative the product is considered to be. Table 8 illustrates the details of the knowledge context factor.

Table 8. Knowledge Context (Factor 6)

	More Adaptive				More Innovative
Knowledge Context	Requires knowledge available within a trade related to the given system.	Requires knowledge from different areas within an industry related to the given system.	Requires knowledge from other industries.	Requires knowledge from different fields of science	Requires knowledge from many disciplines and fields.

To assess a product using the new instrument, each factor is assessed and given a rating value from 1 to 5 (see Table 2), with 1 being most adaptive and 5 being most innovative. The scores for the six factors are added and averaged to obtain the mean product score for creative style. For the purpose of this study, each factor is weighted equally.

Applying the Creative Style Assessment Instrument: An Extended Example

To demonstrate the application of the creative style assessment instrument, we will examine a variety of fastener products as they progress from early garment fasteners to zippers and other related products. This brief history of fasteners comes from Petroski's text on invention and design[20], a valuable resource for condensed accounts from design history. In each case, we will provide a short description of the product in its historical context, followed by the completed style assessment instrument for that product. Please note that due to the brevity of these case studies, our evaluations must be considered approximate; even so, this exercise will give readers an idea of how the instrument can be used.

Howe's Fasteners for Garments: In the early 1800s, the fastening of boot buttons and hooks was a daily, time-consuming challenge. In 1851, Elias Howe, Jr., was granted a patent for a fastening device composed of a line of metal clasps that grasped two sections of beaded fabric, bringing the sections together (or pulling them apart) as the clasps were slid up or down. As with most inventions, Howe's fastener addressed shortcomings associated with the existing way of doing things; it made fastening garments easier and allowed people to do so more quickly. Unfortunately, Howe's fastener was not easy to implement: the clasps had to grip the beaded fabric exactly, and it was difficult to maintain this connection. If someone sat on the fastener, the clasps bent and became too tight or too loose, causing the entire system to break down. Additionally, using the fastener too often eventually caused the fabric to fray, making the product unreliable over time[20].

When analyzing Howe's fastener in terms of technical change, it was a fairly radical solution that could be used for more than one purpose, such as binding garments, securing boots, and fastening other articles together; from this perspective, the product was more innovative. With regard to acceptability, Howe's fastener was easily seen to be a relevant solution to a well-understood problem; it could therefore be considered more adaptive with respect to this factor. However, this product was by no means easy to implement, so for feasibility, it could be considered highly innovative. When looking at efficiency, Howe's fastener was more adaptive because it immediately improved upon the existing system, and the benefits were seen quickly. With regard to method and knowledge context, we have less information; because Howe used methods from his own area of specialization (the garment industry), the fastener might be considered more adaptive in terms of method, and the knowledge context might be placed in the middle of the continuum. Taking these evaluations as a whole, Howe's fastener received a mean creative style rating of 2.7, as illustrated in Table 9.

Table 9. Assessment of Howe's Fasteners for Garments

FACTORS	More Adaptive <------ 1	2	3	4	5 ------> More Innovative
Type of Technical Change				x	
Acceptability	x				
Feasibility					x
Efficiency	x				
Method		x			
Knowledge Context			x		
TOTALS (by column)	2	2	3	4	5
MEAN SCORE (2.7)	<-----------------------------X-->				

Judson's Slide Fasteners: Whitcomb L. Judson, a Chicago mechanical engineer, also invented a clasp locker for shoes. He applied for a patent in 1851, but before it was granted, he applied for a second that improved upon his invention. The original patent would have altered the way shoes were manufactured; his second solution was a shoe fastening device that could be laced into existing shoes. This made it more feasible; in addition, the product could also be used anywhere that called for clasps. Judson continued to improve upon the shortcomings in his design; the clasps' sharp edges and pointed ends caused the fabric they were fastening to tear, and manufacturing the parts was tedious. Judson soon replaced the chains of his original design with hooks and eyes that were fastened directly to the fabric, but this required a new machine to manufacture the necessary parts. Gideon Sundback, an electrical engineer, was hired to help with the machinery and development of the hook and eye fasteners. Combining Judson's mechanical engineering methods with electrical engineering expertise resulted in a more effective fastening product[20].

While Judson's fastener was an improvement on Howe's work, it was a more innovative solution in that it required a new system of production. The product had several shortcomings, but it was eventually well accepted. Because improvements were constantly being made to the original form of this product, we can infer that the efficiency was not immediate, with benefits coming somewhat later in the game. In addition to the need for retooling, we can also see that techniques and knowledge from several engineering fields were required. From this brief analysis, Judson's slide fastener received a mean creative style rating of 3.3, as shown in Table 10.

Table 10. Assessment of Judson's Slide Fasteners

More Adaptive <------------------------------------> More Innovative

FACTORS	1	2	3	4	5
Type of Technical Change					x
Acceptability		x			
Feasibility				x	
Efficiency				x	
Method			x		
Knowledge Context		x			
TOTALS (by column)	0	4	3	8	5
MEAN SCORE (3.3)	:---X---------------------------------				

Sundback's Hookless Fasteners: Sundback (Judson's partner) knew that the hooks were the most troublesome parts of Judson's fasteners; in 1914, he filed for a patent that Petroski[20] calls a "radical departure in principle from the design of earlier slide fasteners." This new product represented over twenty years of design, redesign, development, and implementation; it resembled today's version of the zipper in many ways, but it still had a very inefficient manufacturing process. After many years, Sundback eventually developed a production machine that worked quickly, efficiently, smoothly, and reliably. The new "hookless" fasteners were used for crucial items such as mail bag carriers and flying suits in World War I, but they were not yet incorporated into other clothing. Thus, the benefits of this new fastener were seen in some markets, but not all[20].

As Petroski notes, these hookless fasteners were a radical departure that called for redesign of most related systems. Because the hooks of previous designs were their least desired feature, these new hookless fasteners were readily accepted. The new fasteners were still difficult to implement, however, and were only used in certain contexts, so they were not as feasible as desired. In addition, many attempts, experiments, and years of study were necessary before arriving at a successful solution. Little is known about the method and knowledge context for the hookless fasteners, so we have placed them in the middle of the continuum. Overall, hookless fasteners seem to be more innovative when compared to the previous two products we analyzed, but they are not extreme in this regard (mean creative style score = 3.5), as shown in Table 11.

Table 11. Assessment of Sundback's Hookless Fasteners

FACTORS	1 (More Adaptive)	2	3	4	5 (More Innovative)
Type of Technical Change					x
Acceptability	x				
Feasibility				x	
Efficiency					x
Method			x		
Knowledge Context			x		
TOTALS (by column)	1	0	6	4	10
MEAN SCORE (3.5)				X	

Velcro®: In 1948, George de Mestral developed the idea for Velcro after studying the "stickiness" of woodland cockleburs. His idea seemed sound, but implementation proved difficult. When de Mestral approached manufacturers, they were skeptical because his idea was so unusual. Eventually, a textile plant in Lyon, France began working with de Mestral to improve the Velcro design, and it took nearly six years to turn his idea into reality. The first factory to produce Velcro opened in 1957, and soon, over 60 million yards were being produced each year. Velcro did not replace the zipper as de Mestral had envisioned, but it still proved to be a very successful and important product[20].

Velcro represents a radical change from previous products in terms of its technical structure. Manufacturers found the idea difficult to accept, and it took years to bring the product to market. The original purpose of Velcro was to replace the bulky zipper, but after several years, this had still not occurred – use of the product seemed uncertain. Only years later were the benefits of Velcro finally recognized. Implementing de Mestral's idea required new tools and manufacturing methods, and the required knowledge was also diverse (engineering, biology). Of the products considered thus far, Velcro might be considered the most innovative, as shown in Table 12 (mean creative style score = 4.7).

Table 12. Assessment of Velcro®

FACTORS	1 (More Adaptive)	2	3	4	5 (More Innovative)
Type of Technical Change					x
Acceptability					x
Feasibility				x	
Efficiency					x
Method					x
Knowledge Context				x	
TOTALS (by column)	0	0	0	8	20
MEAN SCORE (4.7)					X

Plastic Zippers: As engineers began improving upon existing zippers, several companies began competing in the process. Borgada Madsen was the first inventor to develop a completely plastic zipper. Not only did this new product solve the problem of snagging, but it also had the advantage of being waterproof and airtight. This zipper clearly had the potential to enter markets other than the clothing industry, but it took many years of hard work and marketing to create acceptance. Madsen's invention rights were sold to a company called Flexigrip, which began marketing the zipper more heavily in the clothing industry. Because this zipper was all plastic, it could be heat welded into fabric (as opposed to being sewn in), thereby reducing the risk of wear and tear. With these new improvements, plastic zippers soon became very popular in the fashion industry[20].

Plastic zippers represented moderate modifications to existing systems that involved many different potential uses. Although it seemed like a wonderful invention, it still took a long time to convince the public to accept it. In terms of feasibility, it did not cost much to make these new plastic zippers, and the fact that they were now made of plastic actually made the manufacturing process run more smoothly, although the product had its quirks. Overall, this seems a more adaptive development within the line of fastener products, as shown in Table 13 (mean creative style score = 2.7).

Table 13. Assessment of Plastic Zippers

FACTORS	1 (More Adaptive)	2	3	4	5 (More Innovative)
Type of Technical Change				x	
Acceptability				x	
Feasibility		x			
Efficiency			x		
Method		x			
Knowledge Context	x				
TOTALS (by column)	1	4	3	8	0
MEAN SCORE (2.7)	------------------------------X------------------------------				

Ziploc Bags®: After convincing the clothing industry that the plastic zipper was a useful product, Flexigrip began using the plastic zipper for other items, such as briefcases and pencil cases. Later, the idea of plastic bag fasteners was introduced, but manufacturing these was found to be costly and inefficient. Eventually, a Japanese inventor (Kakuji Naito) developed a new method to make plastic bags with the zipper closure integrated directly into the bag, and in 1962, Minigrip, Inc. became the first to produce them. Because these were so unconventional, it was difficult to get buy-in for the product; many manufacturers believed that users would not understand how to work the new re-closable bag. Eventually, however, the value (and fame) of these re-closable bags became widespread[20].

Ziploc® bags were a radical change compared to the previous zipper-like products, and because they were so unconventional, they were not readily accepted at first. Producing these bags was also costly initially, but with new production designs, implementation became easier. As far as efficiency is concerned, there were few immediate benefits, but in the long term, Ziploc bags have become almost indispensable. New tools had to be used in their production, while the knowledge context was somewhat diverse. Overall, Ziploc bags seem to be a moderately innovative product (mean creative style score = 3.8), as shown in Table 14.

Table 14. Assessment of Ziploc® Bags

FACTORS	1 (More Adaptive)	2	3	4	5 (More Innovative)
Type of Technical Change					x
Acceptability				x	
Feasibility		x			
Efficiency				x	
Method					x
Knowledge Context			x		
TOTALS (by column)	0	2	3	8	10
MEAN SCORE (3.8)	:---X--------------------------				

Benefits, Limitations, and Future Work

In evaluating the results of this research thus far, we will consider both the general framework for product assessment that we recommended early in this paper and the new style assessment instrument introduced in its latter sections. In the first case, Adaption-Innovation theory and its general, practical application are well-established in many fields, including education, healthcare, management, and science; we believe that it can also provide a strong foundation for the analysis of creativity in the design domain. In particular, the clear distinction A-I theory makes between creative level and creative style offers a promising approach to sorting out the evaluation of creativity where products are concerned. What is required now is an in-depth study of the specific product features that should be associated with the level and style of a design/product, respectively; Table 1 represents a good beginning, but it must be thoroughly vetted and revised as necessary.

With regard to the creative style assessment instrument we have presented here, it offers both immediate benefits and further challenges as well. While the examples used to illustrate its application are brief (and in some cases incomplete), they demonstrate the generally straightforward mechanism for its use. However, the importance of having sufficient information (both technical and historical) to assess a given product accurately cannot be underestimated. Also at issue are the factors themselves and their weighting; one might argue that the six factors we have chosen exhibit some overlap and could be defined more tightly. Based on the response to this preliminary work, we will examine and refine the factors, including a reevaluation of their relative weights. In conclusion, the instrument is a prototype (based on sound theory); further testing and validation will be required before it is ready for general use.

Once the product assessment instrument is finalized, validated, and tested, its use in the design classroom might take several forms. First, the factors on which it is based could be used to define the desired characteristics and/or constraints of a particular design (e.g., the product can represent a moderate revision of the state-of-the-art with moderate costs involved, but its efficiency and acceptability should be almost immediate). Then, with these expectations in place, students' designs could be formally evaluated using both the creative style assessment instrument and other design criteria related to creative level (e.g., reliability, precision, complexity). In addition, we hope to use this instrument in conjunction with the KAI to explore the relationship between the creative style of student designers and the respective styles of the products they create.

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