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THE POTENTIAL OF CREATIVITY METRICS FOR MECHANICAL ENGINEERING CONCEPT DESIGN

Sarah Oman[1] and Irem Y. Tumer[1]
(1) Oregon State University

ABSTRACT

This paper endeavors to explore how creativity factors into the early stages of concept design in engineering and how to quantify that creativity using metrics. Specifically, prototype designs from a junior-level design course are evaluated using design metrics that evaluate a set of ideas based on novelty, variety, quality, and quantity. Revisions to the metrics are presented in this paper in order to combine the novelty and quality aspects of creativity to evaluate individual ideas within a set of designs during the concept design phase. As creativity has become a major requirement for designers and engineers in the 21st century, these and other related metrics could play an important part in the success of companies. Innovative products provide companies with a competitive advantage in the market as well as stimulating the economy. Creativity metrics will enable them to choose the more innovative designs in the beginning stages of concept design, reducing time and cost associated with implementation of designs that are not creative or innovative. Using the creativity metrics in an educational setting will foster effective creative learning. This paper will go into detail about the revision and implementation of an "Innovation equation" on a real-world set of designs generated by a junior-level mechanical engineering design class.

Keywords: creativity, innovation, concept design phase, design metrics

1 INTRODUCTION

Engineering design has evolved greatly in the last few decades, but Buhl most concisely defined engineering and design over 40 years ago:

> "In engineering, we are interested in applying man's intellect to satisfy mankind's physical and social needs through the use of the information and theories acquired in science. A designer is one who satisfies mankind's needs through *new* answers to *old* problems [1]."

In today's terms, "new answers" involve creative ideas and taking risks by going outside an engineer's comfort zone, i.e., their domain experience [2]. To be creative one must "trust things that are alien, and alienate things that are trusted [3]." With this in mind, the design community has spent the last several decades creating methods of ideation, many of which have been successful in aiding designers from all disciplines, and some that specifically targeted engineering in order to aid innovation [4, 5].

As design ideation and the engineering process become more and more streamlined, the need for more innovative solutions increases greatly. To this regard, there has been a substantial increase of research in methods of ideation and increasing creativity in design, such as TRIZ/TIPS (the Theory of Inventive Problem Solving) and Design-By-Analogy [6]. As more companies search for creative or innovative design for future products in order to market more profitable merchandise, a problem arises in finding a means to compare designs to justify one being more creative than the other.

In spite of the limited research in engineering design creativity (compared to other fields' research in creative design methods); several methods have been applied from other fields, such as psychology, to engineering with positive results. It is argued that, by using metrics to quantify the creativity of different design methods, engineers can better determine which method is suited for their creative design purposes using quantitative results.

To address this need, Shah, et al. created metrics to "experimentally evaluate the effectiveness of these [ideation] methods for different kinds of design problems [7]." These metrics analyze four areas of the interest in individual designs and groups of designs: novelty, variety, quality, and quantity. Novelty is how new or unusual a single idea is compared to what is expected. Variety is measured as how much a set of ideas span the solution space; lots of similar ideas are considered to have less variety as a whole and thus the method being evaluated has less chance of finding a better idea in the solution space. Quality measures how feasible a single idea is as well as how much it satisfies design requirements. Quantity is the total number of ideas developed using the method being evaluated, under the assumption that the more ideas there are, the greater the chance of creating innovative solutions.

This paper endeavors to explore how creativity factors into engineering by evaluating a group of designs using these creativity metrics as well as a derived metric that combines the Novelty and Quality metrics into a single equation for innovation. The metrics are combined under the assumption that, by combining the equations into one, this single Innovation Equation can then be implemented on a real-world set of designs generated by a junior-level mechanical engineering design class. The Innovation Equation is named to place emphasis on the goal that the most creative ideas will produce innovative products for today's rapidly changing economy [8]. The implementation of the metrics for Novelty and Quality and the new Innovation Equation are described in Section 5 of the paper.

The end goal of these analyses is to understand how designers and engineers can evaluate a group of ideas to determine the most creative product in the set. As creativity has become a major requirement for designers and engineers in the 21st century, these metrics and revisions could play an important part in the success of companies. They will be able to choose the more innovative designs in the beginning stages of concept design, hence potentially reducing time and cost associated with the development of designs that are not as creative. The sooner a company knows what the most creative product is, the sooner they can capitalize on the market and profit from it [9].

The motivation behind this work to find creative ideas and innovative products is simple on the most basic level: innovation sells in a dynamic economy. However, to develop innovative products, one must know how to pick out the creative ideas from the usual, unoriginal ideas. Then the creative ideas will produce products that respond to the changing wants and needs of the population [9].

2 DEFINING CREATIVITY

Creativity in the broadest terms is simply the ability to look at the problem in a different way or to restructure the wording of the problem such that new and previously unseen possibilities arise [10].

Cropley and Cropley describe the opposite of creativity, *convergent thinking*, as "too much emphasis on acquiring factual knowledge … reapplying it in a logical manner … having clearly defined and concretely specified goals … and following instructions." Their description of *divergent thinking* correlates with several other definitions of creativity, stating that it "involves branching out from the given to envisage previously unknown possibilities and arrive at unexpected or even surprising answers, and thus generating novelty [11]."

Several other sources mention novelty in their definitions of creativity, stating an idea is creative if it both novel and valuable or useful [12, 13]. Shah, et.al. also refer to novelty frequently as well as quality of the idea as it pertains to satisfying initial requirements in creative designs [14].

Combining the definitions, creativity can be described as *a process to evaluate a problem in an unexpected or unusual fashion in order to generate ideas that are novel and useful.*

It should be noted that creativity and innovation have been used interchangeably by many, but are two very different concepts. Creativity in its simplest terms is the creation of original and novel ideas that are useful, while innovation is the implementation of those creative ideas. In this sense, the metrics discussed in this paper measure the creativity of the ideas, with the goal of implementing the Innovation Equation so that engineers will produce innovative products from those creative designs.

During the conceptual design phase, a designer begins with loose constraints and requirements and must slowly build an understanding of the problem and possible directions to the solution. The goals of the problem are vague and, in many cases, there is no clear definition of when the design task is complete and whether the design is progressing in an acceptable direction [15]. This is the motivation behind the creation of many design and creative ideation methods such as TRIZ/TIPS and Synectics [16].

The creative process in any method of ideation begins with the environment the designer is in because external influences can greatly increase or decrease creative insight through inspiration [2]. External influences can come from many sources and differ between domains, experts and novices, and on an individual basis. Studies have been conducted to determine the optimal combination of inspirational sources to foster creative design [17].

Furthermore, forced but structured stimuli have been proven to aid in creative processes. Methods of ideation must be careful with this fact, as negative stimuli can be detrimental, such as stimulus that sparks off-task conversations [18].

Unfortunately, many designers opt not to use ideation methods because of the seemingly cumbersome steps that create long bouts of work, "in which doubt, ambiguity, and a lack of perseverance can lead people to abandon the creative process [19]."

Thus, effective methods of ideation should be, at minimum, environmentally controlled, stimulating, and engaging to the subjects. Other aspects of creativity can include thinking outside the box by evaluating the assumptions to a problem and then, "imagining what is possible if we break them [20]."

A perfect example of an effective method of ideation that works in all domains is the concept of Design-By-Analogy. The basis of this process is the idea of using inspiration of something unrelated to the solution, such as observing a bat's wing and applying its functionality and form to the design of ship sails [21]. The greatest advantage to this method of creative ideation is that it can be used by both novices and experts. Experts tend to use analogies more in their work due to their knowledge and experience, but it is said that novices benefit more from analogy [6]. With the increase in interest in the past decade or so in analogous design, several methods have been developed to increase the effectiveness of designing by analogy, such as applying metrics to identify similar products or ideas [22] or using a hierarchical system of synonyms to identify new possible designs through visual analogy [6, 23].

Just like in all other domains such as architecture or chemistry, engineering design has its own unique requirements and constraints within the creative process. Creative engineering is bounded by the functionality and capability of the system being designed (i.e., it would be largely impractical to design an HVAC system for a motorcycle whereas a biochemical designer could develop a cure for a certain disease and find it cures another disease). Engineers rely more heavily on satisfying requirements of the particular problem, and usually are unable to effectively think outside the box, or if they do think outside the box, it usually becomes improbable (defying gravity or ignoring laws of physics, for example).

The best definition for creativity of engineering products is provided by Cropley and Cropley (2005) in which creativity is a four-dimensional, hierarchical model that must exhibit relevance and effectiveness, novelty, elegance, and 'generalizability' [11]. In this regard, relevance must be satisfied and refers to a product simply solving the problem it is intended to solve. If only relevance is satisfied the solution is *routine*. If the solution is relevant and novelty is also satisfied as described previously in this section, then the product/solution is *original*. When the product is *original* and also pleasing to look at and goes beyond only the mechanical solution, it is *elegant*. Lastly, when the solution is *elegant* and generalizable such that it is broadly applicable and can be transferred to alternate situations to open new perspectives, then the product is *innovative* [11].

This definition is unique in that it places emphasis on having a product not only satisfy the current problem, but also satisfy other or future problems through the 'generalizability' requirement. However, it does not say that if it does not satisfy the generalizability requirement that the solution is not creative, just that it is not completely innovative by Cropley and Cropley standards. This definition by Cropley and Cropley allows for designers and engineers to rank designs as a comparative method, but within each rank (routine, original, elegant, and innovative), there are no standards to differentiate one design being more elegant than another elegant design, for example.

3 QUANTIFYING ENGINEERING CREATIVITY

With the knowledge that engineering design has unique requirements, the question becomes whether the general ideation methodologies that are applicable across all domains are effective in the engineering domain. To answer this question, the metrics previously mentioned have been developed by Shah et.al. to compare the different methods based upon any of four dimensions: novelty, variety, quantity, and quality [7]. The methods can be analyzed with any or all of the four dimensions, but are based on subjective scoring, so that the most important functions of a design are given the greatest emphasis.

3.1 Novelty

Novelty is how new or unusual an idea is compared to what is expected. The metric developed for it is:

$$M_N = \sum_{j=1}^{m} f_j \sum_{k=1}^{n} S_{Njk} p_k \quad (1)$$

M_N is the novelty score for an idea with *m* functions and *n* stages. Weights are applied to both the importance of the function (f_j) and importance of the stage (p_k). S_N is calculated by:

$$S_{Njk} = \frac{T_{jk} - C_{jk}}{T_{jk}} \times 10 \quad (2)$$

T_{jk} is the total number of ideas for the function *j* and stage *k* and C_{jk} is the number of solutions in T_{jk} that match the current idea being evaluated. Multiplying it by ten normalizes the outcome.

3.2 Variety

Variety is measured as how much the ideas generated span the solution space; lots of similar ideas are considered to have less variety and thus less chance of finding a better idea in the solution space. The metric for variety is:

$$M_V = \sum_{j=1}^{m} f_j \sum_{k=1}^{4} S_k b_k / n \quad (3)$$

M_V is the variety score for a set of ideas with *m* functions and 4 levels. The analysis for variety uses four levels to break down a set of ideas into components of physical principles, working principles, embodiment, and detail. Each level is weighted with scores S_k with physical principles worth the most and detail worth the least. Each function is weighted by f_j and the number of concepts at level *k* is b_k. The variable *n* is the total number of ideas generated with the method.

3.3 Quality

Quality measures how feasible the set of ideas is as well as how much they satisfy design requirements. The metric for it is:

$$M_L = \sum_{j=1}^{m} f_j \sum_{k=1}^{2} S_{jk} p_k \Big/ \left(n \times \sum_{j=1}^{m} f_j \right) \quad (4)$$

M_L is the quality rating for a set of ideas based on the score S_{jk} at function *j* and stage *k*. Weights are applied to the function (f_j) and the stage (p_k) and *m* is the total number of functions. The denominator is used to normalize the result to a scale of 10.

3.4 Quantity

Quantity is simply the total number of ideas, under the assumption that, the more ideas there are, the greater the chance of creating innovative solutions. There is no listed metric for quantity as it is a count of the number of concepts generated with each method of design.

4 CREATIVITY METRICS REVISION

4.1 Overview of Revisions

With these metrics, ideation methods can be compared side by side to see whether one is more successful in any of the four dimensions. However, the metrics are not combined in any way to produce an overall creativity score for each method. Shah, et.al, best state the reasoning behind this: "Even if we were to normalize them in order to add, it is difficult to understand the meaning of such a measure. We can also argue that a method is worth using if it helps us with any of the measures [7]." There is added difficulty to combining all of the metrics as Novelty and Quality measure the creativity of individual ideas, while Variety and Quantity are designed to measure an entire set of ideas generated. Thus Variety and Quantity are irrelevant for comparing different ideas generated from the same method. With this in mind, several of the above metrics can be manipulated to derive a way to measure the overall creativity of a single design in a large group of designs having the same requirements.

The initial motivation behind the combination of metrics stemmed from the mechanical engineering course. The professors and teaching assistants for the course wanted a way to assess the creativity of the final design of each team in the course, and the metrics developed by Shah, et.al. were the most appropriate for this purpose. However, the Variety and Quantity sections could only evaluate a group of ideas, so only the two sections that could evaluate individual ideas from the group, Novelty and Quality, could be used. Also, the original metrics focused not only on the conceptual design stage, but also implementation and further. As the course only focused on conceptual design for the junior-level engineering students, the metrics would have to be further revised to account for only the conceptual design phase. Lastly, the professors and TAs wanted to be able to assign a single creativity score to each team, but the purpose of the original metrics was the ability to assess ideation methods for any of the four sections. The four areas for analysis were never intended to be combined, thus the creation of the Innovation Equation.

This paper illustrates how to implement the original Novelty metric and a modified version of the Quality metric on a set of designs from a mechanical engineering design course. Then the two metrics are combined into an "Innovation equation", which is the first attempt to help designers and engineers assess the creativity of their designs quickly from the concept design phase. The Innovation Equation is aptly named as it aims to provide engineers and companies with the most creative solution so that they may create the most innovative product on the market. Emphasis on this study is placed solely on the concept design stage because researchers, companies, and engineers alike all want to reduce the amount of ineffectual designs going into the implementation stages.

As the metrics were not intended to be combined into one analysis, the names of variables are repeated but do not always represent the same thing, so variable names must be modified for consistency. Also, the equations were written to evaluate ideas by different stages, namely conceptual and embodiment stages. However, as the analysis is only concerned with the conceptual design stage and does not involve using any existing ideas/creations, the equations will only be evaluated at the conceptual stage, i.e., n in the Novelty equation equals one and p_k is not used.

4.2 Revised Metrics

The major differences between the metrics discussed in Section 3 and the Innovation equation used in this paper are the reduction of the summations to only include the concept design level, and the combination of Novelty and Quality into one equation. The resulting Innovation Equation will aid in quick and simple comparison between all the designs being analyzed. This equation is rather simple as it just takes each of the creativity scores for Novelty (M_N) and Quality (M_L) and multiples each by a weighted term, W_N and W_L, respectively. These weights may be changed by the evaluators based on how important or unimportant the two sections are to the analysis. Thus, these analyses are very subjective, based on customer and engineer requirements. This could prove advantageous as the analyses can be applied to a very wide range of design situations and requirements. Also, Brown (2008) states it most concisely; "the advantage of any sort of metric is that the values do not need to be 'correct', just as long as it provides relative consistency allowing reliable comparison to be made between products in the same general category [24]."

Note that both equations for Novelty and Quality look remarkably similar, however, the major difference is with the S_N and S_L terms. These terms are calculated differently between the two creativity sections and are also based off different information for the design.

$$M_N = \sum_{j=1}^{m} f_j S_{Nj} \tag{5}$$

$$S_{Nj} = \frac{T_j - R_j}{T_j} \times 10 \tag{6}$$

$$M_L = \sum_{j=1}^{m} f_j S_{Lj} \tag{7}$$

$$I = W_N M_N + W_L M_L \quad (8)$$

Design Variables:

- T_j = number of ideas total produced for function j in Novelty
- i = number of ideas being evaluated in Quality
- f_j = weight of importance of function in all equations
- R_j = number of similar solutions in T_j to function being evaluated in Novelty
- S_{Lj} = score of quality for function j in Quality
- S_{Nj} = score of novelty for function j in Novelty
- W_N = weight of importance for Novelty
- W_L = weight of importance for Quality
- M_N = creativity score for Novelty
- M_L = creativity score for Quality

5 IMPLEMENTATION OF METRICS TO REAL-LIFE DESIGNS

The ME 382 junior-level mechanical engineering design course at Oregon State University is a ten-week course developed around the annual ASME design competition. The Fall 2008 term had 28 teams of 3-4 people design a robotic device that could drive over 4" x 4" barriers, pick up small rocks, and bring them back to a target area on the starting side of the barriers.

Each team went through a rigorous design process that began with several weeks of strict design exercises in order to promote the conceptual design phase. Less emphasis was put into the implementation of designs during this course. Example design exercises that everyone participated in include a Sticky Note Ideation method and a Morphological Matrix [5]. The Sticky Note Ideation method involved everyone in their design teams writing down as many plausible and implausible ideas dealing with the design problem as possible; one idea to each Sticky note. At the end of the time limit, everyone in the design team would take turns reading out what they wrote at which point anyone in the group could write more ideas spurred from others. The idea is that the implausible ideas will spark creative, plausible ideas that would not have originally been realized.

The Morphological Matrix involves a round-robin design matrix in which each team member creates a large grid on a piece of paper and begins each row with an idea to satisfy one aspect of the design problem. Then everyone rotates the paper to their right and the next group member uses the previous idea and morphs it into an idea of their own or develops the idea further. This method of ideation is extremely effective in fostering group creativity. Figure 1 is an example of a Morphological Matrix created by one of the design teams for the mechanical engineering design course.

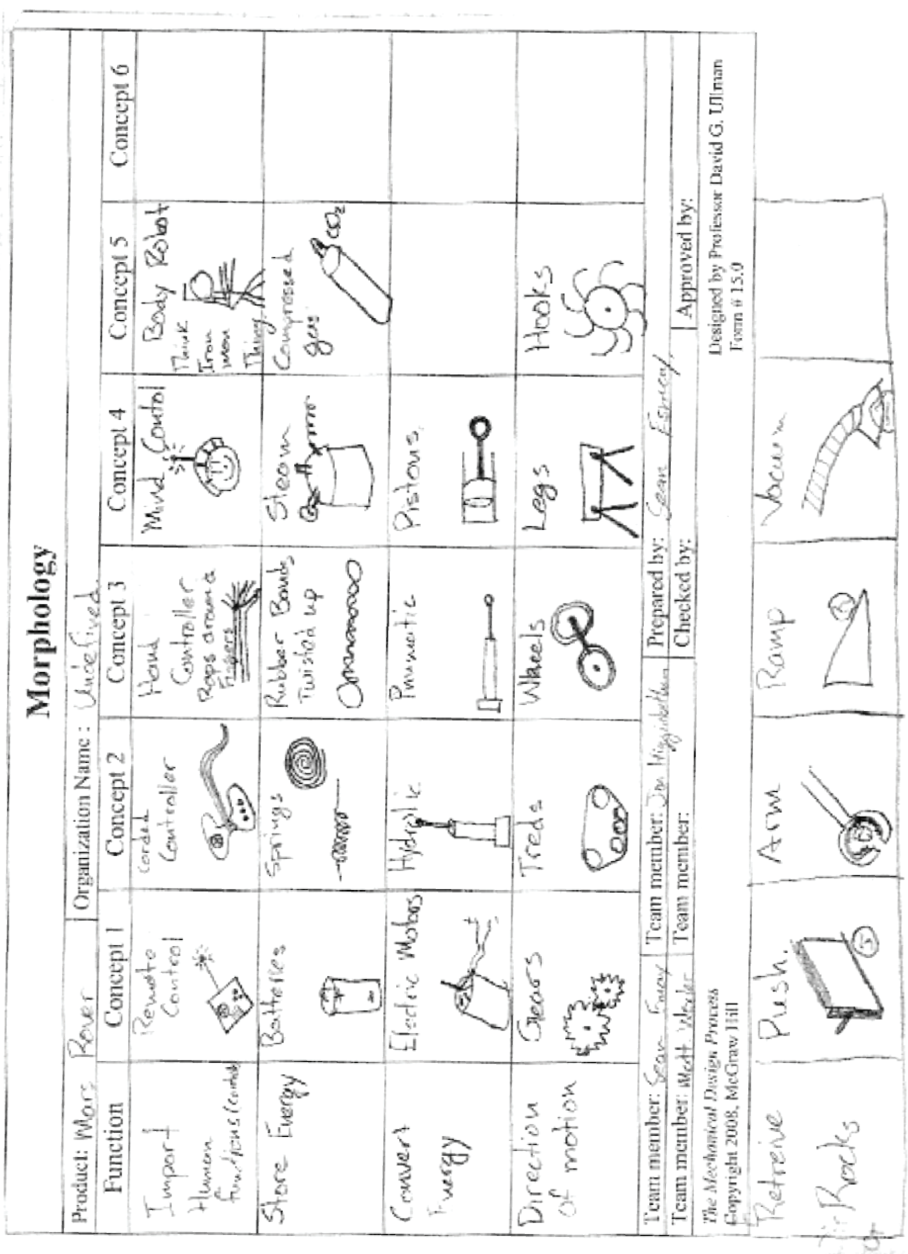
These ideation methods worked to help each design team create their own unique device to compete during the tenth week of the course. Although each device was unique from every other device, it was also very evident that many designs mimicked or copied each other to satisfy the same requirements of the design competition problem. For example, 24 of the 28 designs used a tank tread design for mobility, while only 4 decided to try wheeled devices.

To implement the creativity metrics, each design is first evaluated based on its method of mobility, getting over the barriers, picking up the rocks, storing the rocks, dropping the rocks in the target area, and their controller. These parameters make up the Novelty section of scoring.

Table 1 outlines the different ideas presented in the group of designs under each criterion for the Novelty analysis, followed by the number of designs that used each particular idea. Next to each criteria is the weighted value, f_j, which puts more emphasis on the more important functions such as mobility and less emphasis on less important functions such as what the controller is made out of. Note that all weights in the analysis are subjective and can be changed to put more emphasis on any of the criteria. This gives advantage to those engineers wanting to put more emphasis on certain functions of a design than others during analysis.

The columns of numbers are the R_j values (number of similar solutions in T_j to the function being evaluated in Novelty) and all the T_j values equal 28 for all criteria (28 designs total).

The Quality section of the metrics evaluates the designs individually through weight, milliamp hours from the batteries, the number of switches used on the controller, the total number of parts, and the number of manufactured parts. These criteria were created in order to determine which devices were the most complex to operate, the hardest to manufacture, and the hardest to assemble. The weight and milliamp hour criteria were part of the competition requirements and easily transferred to this analysis. Each device was evaluated and documented in regard to



each of the criteria and then all the results were standardized to scores between 1 and 10.

Figure 1. Morphological Matrix

All the devices were evaluated only at the concept design stage and not on the implementation of the teams' ideas. The students did not have enough time to place adequate attention on the implementation and testing of their devices. This can be said about real-world situations, which could be argument for the analysis of the implementation stage; however, the analysis would not be accurate and consistent for all the devices. Many teams did not have anyone that was familiar enough with electrical devices, while others did not have experience in machine shops to create the ideas that they designed. Lastly, there was not enough time to adequately prepare for documentation of the entire competition in order to evaluate the implementation of the designs. Next year's ME 382 class will provide an opportunity to streamline the analysis and include an evaluation of the implementation stage.

Table 1. Novelty Criteria and Types

Mobility	**f_1= .25**	**Over Barrier**	**f_2= .2**	**Pick up rocks**	**f_3= .2**	**Store rocks**	**f_4= .15**	**Drop rocks**	**f_5= .15**	**Controller**	**f_6= .05**
Track	24	Double Track	4	Rotating sweeper	10	Angle base	11	Tip vehicle	2	Game controller	3
Manuf. Wheels	1	Angle Track	15	Shovel under	8	Flat base	10	Open door	8	Plexiglass	5
4x Design Wheels	2	Single Track powered	2	Scoop in	9	Curve base	2	Mechanized pusher	5	Remote controller	4
8x Design Wheels	1	Wheels with Arm	1	Grabber arm	1	Hold in scoop	3	Reverse sweeper	4	Plastic controller	3
		Wheels with ramp	1			Tin can	1	Open door, tip vehicle	3	Car controller	7
		Angled wheels powered	1			Half-circle base	1	Drop scoop	3	Metal	5
		Tri-wheel	1					Rotating doors	1	Wood	1
		Single track with arm	1					Leave can on target	1		
		Angled track with arm	2					Rotating compartment	1		

With all the variables for the Novelty and Quality sections identified, each device can now be evaluated with the metrics developed by Shah, et al. Once the Novelty and Quality criteria are scored for each device, the Innovation equation can be implemented to determine the most overall creative design of the set.

Table 2 lists each robot with an identifying name and their respective Novelty and Quality scores. The names have two numbers, corresponding to the class lab section and team number, respectively. The total score *I* from the Innovation equation following the Novelty and Quality scores is calculated using the weights W_N and W_L, where W_N equals 0.6 and W_L equals 0.4, giving more priority to Novelty. The subjectiveness of the metrics is needed so that they can be applied over a wide range of design scenarios. The advantage to its subjectiveness is that the weights can be changed at any time to reflect the preferences of the customers or designers.

As highlighted in Table 2, the device with the highest Innovation score based on the revised metric is Device 1-3, pictured in Figure 2. It is interesting to note that D1-3 remains the highest scoring design of the set until the weights for Novelty and Quality are changed such that Quality's weight is greater than 0.6, at which point D2-4 becomes the highest scoring because of its high Quality score. However, Novelty should be given the higher priority in this analysis because it measures how unique and unusual each device is to satisfy the six criteria mentioned previously. Note that the highlighted definition of creativity discussed in Section 2 places greater emphasis on *novel* and *unusual* and less emphasis on *useful,* i.e., functional criteria represented in the Quality section. The quality section is still very important in the analysis though, as one cannot chose a design based strictly on how unusual it is because that design may not satisfy the requirements of the original problem. Designers and engineers must keep in mind that creative solutions must still place emphasis on the functionality of the design; hence the inclusion of the Quality section in the Innovation equation.

Table 2. Novelty, Quality, and Combined Scores

	D1-1	**D1-2**	**D1-3**	**D1-4**	**D1-5**	**D1-6**		
Novelty	6.107	5.179	8.393	6.25	6.196	5.036		
Quality	5.109	4.36	8.181	8.088	8.944	4.204		
I	5.708	4.851	***8.308***	6.985	7.295	4.703		
	D2-1	**D2-2**	**D2-3**	**D2-4**	**D2-5**	**D2-6**	**D2-7**	**D2-8**
Novelty	4.982	5.482	5.25	6.232	5	6.589	8.071	5.429
Quality	5.771	5.516	6.293	9.615	7.798	6.484	6.834	6.181
I	5.298	5.496	5.667	7.585	6.119	6.547	7.576	5.730
	D3-1	**D3-2**	**D3-3**	**D3-4**	**D3-5**	**D3-6**	**D3-7**	
Novelty	6.821	5.875	6.464	4.964	7.964	5.25	5.25	
Quality	9.119	7.03	7.937	6.545	6.102	8.175	7.736	
I	7.740	6.337	7.053	5.596	7.219	6.42	6.244	
	D4-1	**D4-2**	**D4-3**	**D4-4**	**D4-5**	**D4-6**	**D4-7**	
Novelty	5.286	5.179	6.107	6.768	6.554	8.857	4.964	
Quality	6.55	8.534	8.898	7.634	7.578	5.465	6.933	
I	5.792	6.521	7.223	7.114	6.963	7.500	5.752	

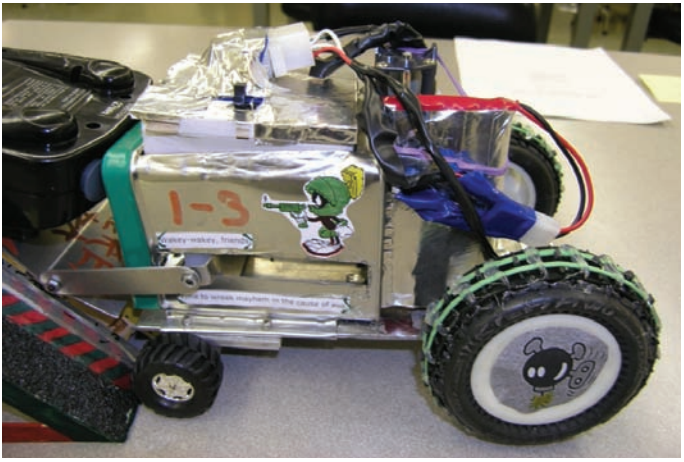


Figure 2. Device 1-3

Thus, it is justifiable that Device 1-3 is indeed the most creative of the group because it embodies the necessary criteria for both Novelty and Quality such that the design is both unique and useful at the conceptual design phase. The design of Device 1-3 is unique because it was the only one to use four manufactured wheels (mobility) and a ramp (over barrier). Its solution for picking up the rocks (shovel under) and storing the rocks (flat compartment) were not quite as unique, but it was only one of five devices to use a mechanized pusher to drop the rocks and only one of four to use a remote controller. The combination of these concepts yielded a high Novelty score.

Its high Quality score is largely due to the fact that it had the lowest milliamp hours and the lowest number of parts of all the devices. It also scored very well for weight and number of manufactured parts, but only had a median score for the number of switches used to control the device.

As stated previously, this analysis only deals in the conceptual design phase and not implementation. The majority of the designs actually failed during the design competition due to many different problems resulting from a time constraint towards the end of the design process. The emphasis in the class was on concept design and team work, not implementation of their design. Only two devices in the 28 designs were able to finish the course and most designs fell apart in some fashion or flipped upside-down when traversing the barrier, which was all expected. Four months later at the regional qualifiers for this ASME competition, the majority of all the competing designs from around the Northwest performed in the same manner as the ME 382 competition even with months of development and preparation.

6 FUTURE WORK

The next step in this research study is to implement the initial Innovation equation along with the original metrics created by Shah, et.al. on groups of designers who are trying to come up with the most creative solutions. By analyzing the methods of creative ideation along with finding which idea from a group is the most creative, any correlation between the method of ideation and the highest scoring creative design can be identified and analyzed. This could provide an idea as to how many generated ideas are optimal for any particular ideation method in order to generate the most creative design within the generated ideas. This will benefit both the academic and professional worlds, as it will aid in teaching how to effectively generate creative solutions. These methods of effective creativity generation can be brought to the professional level to benefit engineers and businesses in generating innovative products.

Given enough resources and time, it is possible that one could derive metrics to assess the value of visualization in design, specifically in the concept generation phase of design. Work is currently being conducted in evaluating how visualization techniques convey the information necessary for designers [25], which will aid in the development of metrics to assess that information. Along with visualization metrics, research is also being conducted into how to quantify the risk of innovative products and the sustainability of concepts, all at the concept generation phase of engineering design. This metrics could then be combined into a metric package that designers and engineers can use to evaluate a set of ideas looking of the optimal idea based on the amount of creativity, risk, and sustainability the idea exhibits.

Future work includes plans for applying these metrics to a controlled high school, university, and/or professional level experiment testing different ideation methods and tools to see which benefits designers the most during the early stages of design in order to produce the most innovative design based on the Innovation equation. The initial test would be easiest to implement on college junior or senior level engineering design classes using any of the aforementioned design tools.

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Contact: Irem Y. Tumer
Oregon State University
Department of Mechanical, Industrial and Manufacturing Engineering
204 Rogers Hall
Corvallis, OR 97331
USA
Phone: +1 541 737 6627
Fax: +1 541 737 2600
E-mail Address: irem.tumer@oregonstate.edu
URL: http://web.engr.oregonstate.edu/~itumer/

Dr. Irem Y. Tumer is Associate Professor in the area of Design in the Mechanical Engineering Department at Oregon State University. Her research focuses on the overall problem of designing highly complex and integrated engineering systems with reduced risk of failures, and developing formal methodologies and approaches for complex system design and analysis. Her expertise touches on topics such as risk-based design, systems engineering, function-based design, failure analysis, and model-based design. Prior to accepting a faculty position at OSU, Dr. Tumer led the Complex Systems Design and Engineering group in the Intelligent Systems Division at NASA Ames Research Center, where she worked from 1998 through 2006 as Research Scientist, Group Lead, and Program Manager. She received her Ph.D. in Mechanical Engineering from The University of Texas at Austin in 1998.

Graduate research assistant Sarah Oman joined OSU from the University of Idaho and is pursuing a PhD in mechanical engineering. Oman's doctoral research, which is being directed by Dr. Irem Tumer, addresses quantification and optimization of creativity, sustainability, and the risk inherent with creativity in automated concept generation in mechanical systems design.