AC 2010-2278: FROM BRAINSTORMING TO C-SKETCH TO PRINCIPLES OF HISTORICAL INNOVATORS: IDEATION TECHNIQUES TO ENHANCE STUDENT CREATIVITY

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From Brainstorming to C-Sketch to Principles of Historical Innovators: Ideation Techniques to Enhance Student Creativity

Abstract

The heart and soul of engineering is innovation and our ability to improve the human condition through design. To enrich engineering education, it critical that we advance our teaching in innovation and design processes. This research focuses on the ideation component of innovation through the investigation of a suite of concept generation techniques. These techniques have been developed for engineering education across disciplines and at all levels of curriculum. In this paper, we advance our suite of techniques through the evolution of a method known as "principles of historical innovators." Based on the deployment of the techniques, including the evolved method, at the freshman- and senior-levels, we execute a study to understand if the suite of techniques enables students to generate a large quantity of diverse concepts and if the suite enhances the creativity of the students. Our approach is to pre-survey students regarding a self-assessment of their creativity using Gouge's list of creativity descriptors. A control and experimental group of student design teams across disciplines and class level are then asked to develop as many concepts as possible for their course design projects. The control group only executes a single and well-known method from the suite of concept generation techniques, whereas the experimental group employs the entire suite of techniques. The total number of concepts developed by the teams is evaluated, documenting the number of concepts per ideation technique. The teams are also asked to complete a post-creativity survey. The assessment results from this study show a clear and statistically valid enhancement of the students' creativity, a higher quantity of concepts generated from the suite of techniques, and appreciation of atypical techniques such the "principles of historical innovators."

Motivation and Research Objectives

Innovation and creativity in design are key outcomes for engineering students in our increasingly flat and connected world. The concept generation (CG) step in the design process presents tremendous and unique opportunities for enhancing creativity in students. A variety of techniques specifically to enrich the CG or ideation process inform our research. Based on those influential ideation techniques, as well as original work we have conducted in this area, we have developed a suite of CG techniques to assist in the design projects [1]. The techniques include mindmapping, a modified 6-3-5 or C-Sketch technique, functional decomposition combined with morphological analysis, Theory of Inventive Problem Solving (TIPS/TRIZ), a method to produce products with the ability to transform or reconfigure, a search for cross-domain or far-field analogies, implementation of creativity principles from historical innovators, and a design by analogy technique using a WordNet-based search procedure [2-9,11-12,33]. Figure 1 illustrates the suite of concept generation methods as a distributed collage. The fundamental premise of this suite is to enable designers to develop innovative concepts well beyond those that they would have created through ad hoc or singular, intuitive concept generation techniques. Through a suite of techniques, fixation, group think, and other cognitive barriers may be mitigated, we surmise, leading to an enhanced ability to ideate.

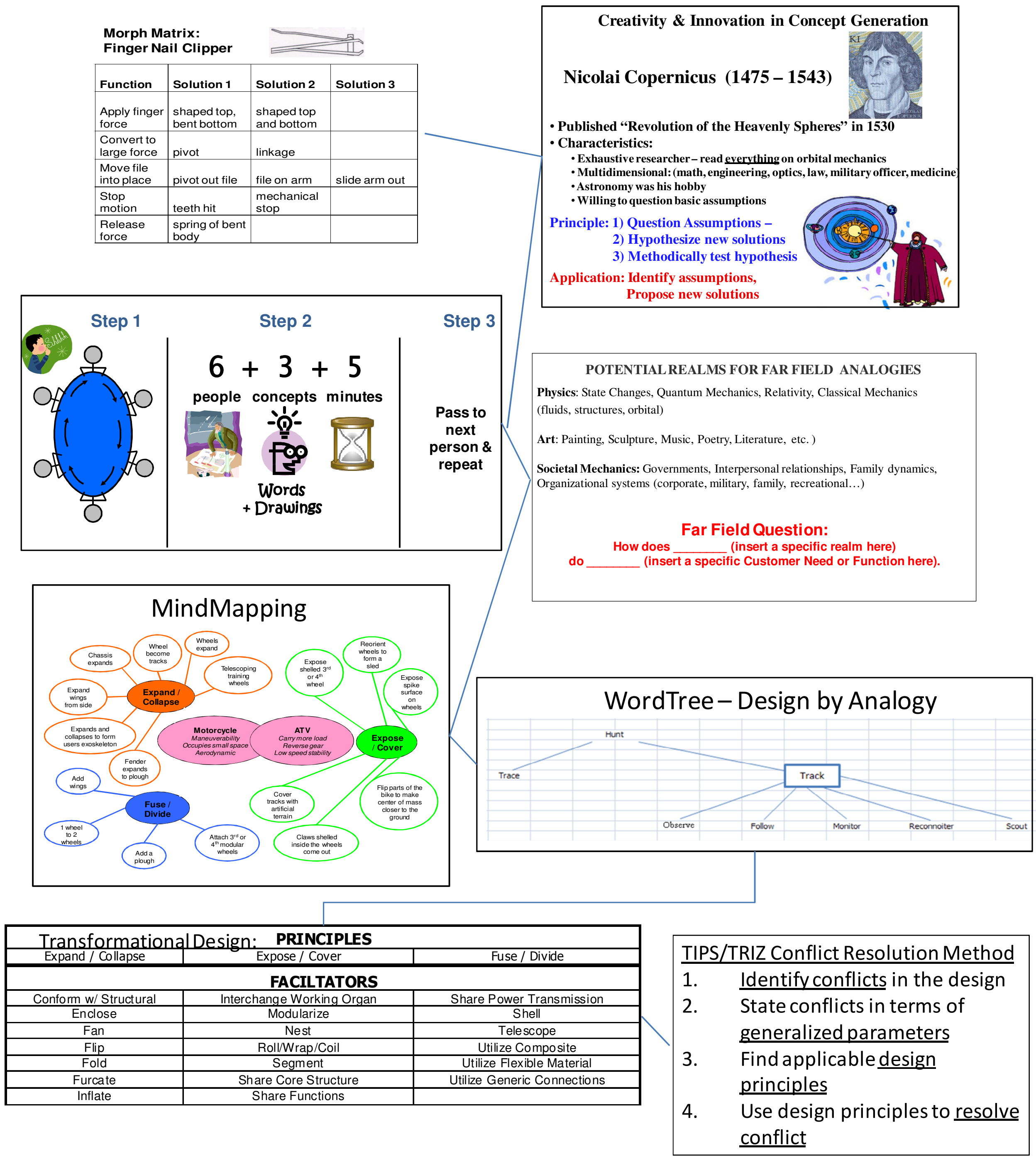


Figure 1. Suite of Concept Generation Techniques

To investigate this premise, we designed and executed a study of student design teams, building on our previous research as reported in (Jensen, et al, 2009) [1]. The study focused on three components: (a) continual advancement of the suite of concept generation techniques; (b) quantitative assessment of a design team's ability to generate concepts using the suite of techniques; and (c) assessment of enhancing students' creativity during ideation activities. The first component of the study focused on evolving the technique known as Historical Innovators (or Historical Innovators' Principles). This technique was recently created with the goal of building upon the successes of past innovators. As part of the technique, students study historical innovators, identify with their life stories and approaches to solving innovation problems. The second and third components of the study seek to measure whether a suite of concept generation techniques increases the abilities of design teams to generate ideas, and, in concert, enhance the creativity of student team members. Quantity of concepts, as a measure of a team's ability to ideate, is recorded for teams across multiple education institutions, across disciplines, and across year of study. Student teams are also asked to perform a self-assessment of their creativity characteristics. The teams perform this self-assessment through a pre- and post-survey during the study.

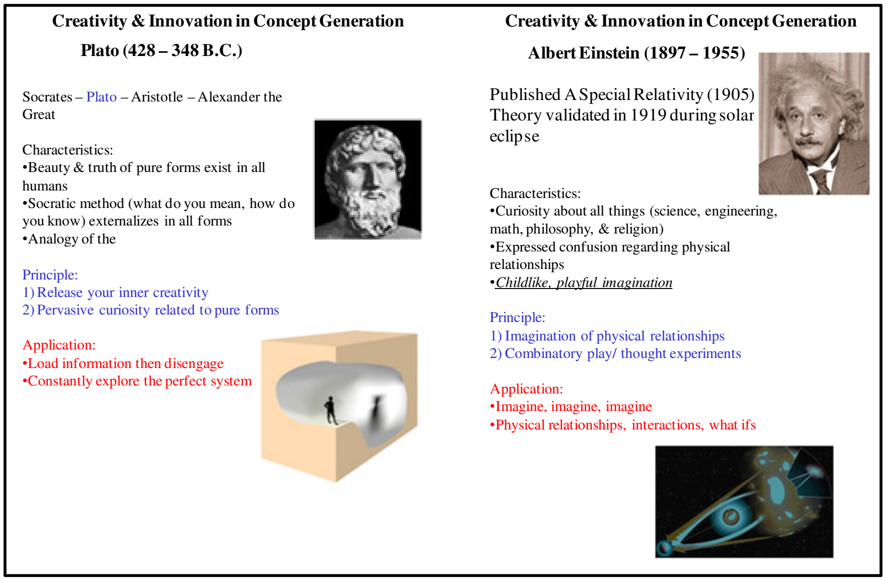
Advancing the CG Suite - Principles from Historical Innovators

As an example of the suite of CG techniques, we consider the implementation of creativity principles from historical innovators. Isaac Newton wrote, "If I have seen farther than others, it is because I was standing on the shoulders of giants" - a phrase that has survived generations to motivate our research on innovation. As part of the CG suite, these innovative giants are introduced as "historical innovators," creating new pathways to ideation. By standing on the shoulders of giants such as Albert Einstein, Marie Curie, Harriet Tubman, and Copernicus (to name a few), ideation is enhanced through the application of the design principles attributed to each historical figure. In our most recent development of this technique, we focus on culturally relevant and ethnically diverse historical innovators, particularly female innovators. Including historical female innovators informs and enriches the CG suite in that each historical innovator brings her own unique and fundamental innovative principles that transcend time and space. Moreover, there continues to be a dearth of female voices and recognition for female role models in engineering education. The inclusion of these notable women sparks creativity at times because of cultural connections in addition to technical directions while providing an appreciation for and pride for diverse backgrounds.

Although significant questions remain on what precise traits exemplify a person's ability to be creative, there is a notion of consensus that history has numerous examples of individuals who have exhibited tremendous creative accomplishments. The concept generation technique of "Historical Innovators" attempts to capture some of the principles that these extraordinary individuals used to accomplish their innovative feats and then apply these principles to the concept generation process. For each of the innovators, we provide background information and a summary of life's endeavors, a set of "innovation principles" and a proposed application of the principles. There are, of course, literally thousands of possible historical innovators that could be used in this technique. We capture but a mere glimpse or silhouette of these thousands, yet even in this glimpse, we enhance and expose students to a wondrous and exciting world of the past, bringing the past to life in our contemporary times.

On whose Shoulders Do We Stand? Inclusion of Diversity in Our Innovation Giants

Nicolai Copernicus, Christopher Columbus, Plato, and Albert Einstein (Figure 2) were first chosen as historical innovators in the CG suite. The basis for initially choosing these historical figures was due to the fact that their principles are quite broad and directly applicable to the CG process. In a concerted effort to consider the inclusion of innovators that can connect to a wide variety of design problems and prompt ideation, we believe that the innovative giants must represent principles and applications that span time and space. Although Copernicus, Columbus, Plato, and Einstein meet those criteria, demographically there is a limit to their representation. It is important that we also include historical innovators that are demographically diverse in gender, race, engineering experiences, and era.



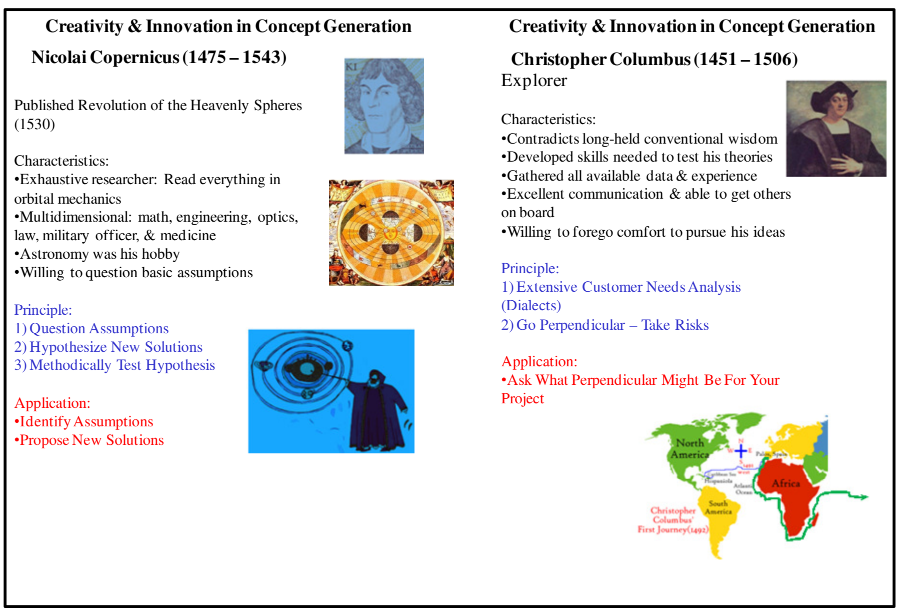


Figure 2. Plato, Einstein, Copernicus and Columbus CG Resources

In seeking out additional historical innovators that represent more diversity, we researched repositories that have a focus of marginalized groups in the history of patented inventions in the United States [e.g., 34-42]. A few of the repositories included only notable African American inventors, others all female patent holders and some that are comprised of celebrating salient inventors who are non-White. From these broad lists, we considered ways that we could still represent diversity of engineering experiences, principles, and applications in the resources for the CG suite. Ultimately, the historical innovators we highlight in the CG suite, in addition to the original aforementioned four, are the following: Marie Curie, Bette Nesmith Graham, Stephanie Kwolek, Harriet Tubman, Charles Drew, and George Washington Carver. Appendix A provides summaries of these historical innovators as provided in the CG suite.

Originally, the historical innovator technique was introduced as part of the capstone design experience at the United States Air Force Academy (USAFA), Department of Engineering Mechanics. We tested the evolved technique with the extended set of innovators at The University of Texas (UT) as part of freshman signature course and a multi-disciplinary senior design projects course. To introduce students to our idea of being inspired by historical innovators, we present an example about how other students have used this model for design ideation. We prompt the discussion with paragon words of wisdom from Isaac Newton, "If I have seen farther than others, it is because I was standing on the shoulders of giants". After students discuss their interpretations of this quote, we describe the idea of becoming inspired by and applying principles of historical innovators in their concept generation. Students then delve into historical references of the innovators, choosing those innovators with which they most identify and intrigue their imaginations.

As part of the historical innovator technique, we present the students with a specific example of how our engineering teams have applied principles of Christopher Columbus to generate an innovative design. Indeed, the designs United States Air Force Academy (USAFA) students invented may not have been imagined had it not been for this cognitive generation technique to enhance their ideas. In a previous project, a USAFA design team was challenged with designing an unmanned aerial vehicle that can survey for a period of time. Some of the considerations in the design included battery life and ability for a camera to perch for surveillance. Initially, Christopher Columbus does not necessarily seem to be a historical innovator that would spark concepts in direct relation to this problem. Therein lays our curiosity about the strength in this concept generation technique. We find this strength in the ability for application of the principles of historical innovators because it can prompt ideas that are non-obvious and novel. This observation is seen in the USAFA example that we share with our students. The non-obvious connection that the USAFA students make with Christopher Columbus is the principle of going perpendicular. By applying this noted and historical principle, they were able to generate an innovative design solution as shown in Figure 3 [10]. The unmanned aerial vehicle (UAV) is able to slow the flying speed and 'go perpendicular' to fly into a solid surface (such as the side of a wall). By being able to 'perch' on the wall, it is able to reserve the battery power. Simultaneously, a camera is able to be released for surveillance. Upon completion of the task, the UAV can fly away and leave the camera for persistent reconnaissance.

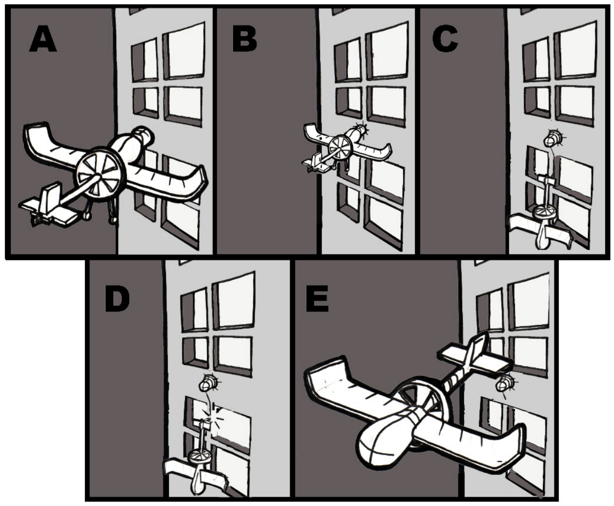


Figure 3. Illustration by R. Kuhr of USAFA's Idea to Go Perpendicular

After the introduction of the cognitive generation technique for the suite and the USAFA example, we facilitate students in practicing this technique with learning about George Washington Carver [Figure 4], one of our new additions to the CG resources. Students work independently and then share their ideas with the entire class and in writing and illustrations. Some of the interesting and exemplar results indicate that their high conceptual understanding of his principles and they are successfully able to apply those principles. One student notes that Washington's invention about shelling peanuts makes him think about a "spinning centrifuge to get cream off the top of milk" as he applies the principle to another problem.

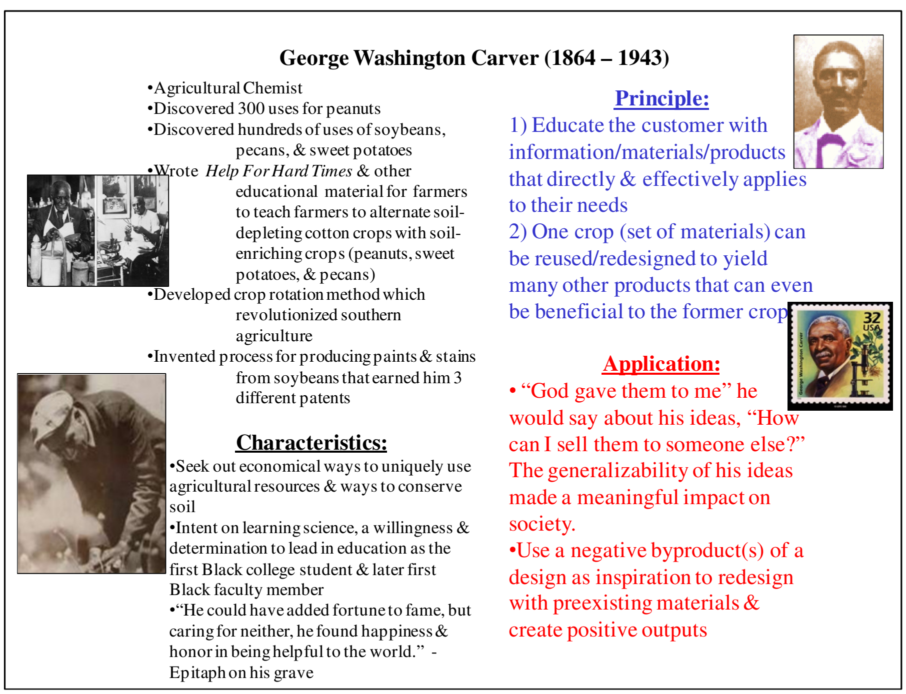


Figure 4. George Washington Carver CG Resource

Choosing Shoulders on Which to Stand: Students See Further in Their Concepts

For their final design projects, students in the freshman signature course at UT invent and prototype a product to solve a problem encountered in their daily life experiences. To present their designs, they tell their own experiences as an inventor – from conception to realization. Within their stories of innovation, we ask them to describe their choice and use of the historical innovator technique in the midst of the CG suite. Indeed, we coached them to be inspired by the resources we provide for them (Appendix A) and also supported them in finding another notable person whose principle(s) may inspire more and better novel ideas for their design.

Certain teams applied principles from historical innovators that we provided in the CG suite resources and the majority of the teams included their own research of a historical innovator (Appendix B). In their reflections about the direct inspiration that historical innovators provide them with during their design process, a number of teams indicated that their historical innovator was the impetus for their final innovative design. The diversity in inventors supports our inclination to consider demographics to include many types of people in our CG suite. Indeed, the diversity and interests represented by the students across gender, year of study, and ethnicity would not have been addressed without a more diverse set of historical innovators. Table 1 illustrates the design inventions and the corresponding historical innovator used by the freshman teams at UT

Table 1. Student Inventions and Corresponding Historical Innovator

STUDENT INVENTION	HISTORICAL INNOVATOR
Pill Dispensing Machine	Thomas Adams: Gumball Machine
Silent Wrapper Opening Device	Hiram Percy Maxim: Maxim Silencer
Multi-Purpose Laundry Device	Sarah Boone: Ironing Board
Multi-Functional Drafting Tool	Karl Elsener: Swiss Army Knife
Self- Guiding Ball Rebounding Device	Copernicus: Revolution and Rotation
2-in-1 Stable Tongue Scraper & Toothbrush	Christopher Columbus: Go Perpendicular
Tangle-Free Headphones Device	Zvi Yemini: Water-Powered Hose Winding Reel

As we continue to understand more about the ways that we can scaffold and enrich creative thinking and problem-solving in engineering education, we look to hone and improve the CG suite. One of the exciting aspects of this research is that the application of principles of historical innovators is an important part of ideation that spans across disciplines. A goal of developing lifelong learners is to find ways to develop skills that will transfer across time and space. We believe that understanding ways to apply key principles to solve your own problems is one of those lifelong skills. Furthermore, we will only improve current and future engineering education experiences when we build on successes of our engineering pasts.

CG Suite Innovation Study

Overview

In an effort to assess the ability of these techniques, including the evolved historical innovators technique, to enhance creativity in our students, a survey is designed and conducted to gauge, at least indirectly, creative ideas before and after the students learned to use the CG techniques. We apply this assessment, as well as concept generation metrics, to a range of inventive design problems solved by our students. Our results show that the implementation of the suite of CG techniques increases the creativity of the students, and produces an increased quantity and variety in concepts. The assessment also indicates that exposure to these CG techniques increases creativity when compared to a control group that were not exposed to the full suite of CG techniques.

Methodology

Teams of undergraduate engineering students are formed at the US Air Force Academy (USAFA) and the University of Texas at Austin (UT for Major Design Experiences (a.k.a., Capstone) in the students' last year of undergraduate work. Teams of students are also created as part of a freshman signature course at UT, entitled "The Engineered World: Products and Innovations" and composed of multi-disciplines (typically not engineering) from across the university. The USAFA and UT teams were formed to meet the following goals:

1. Intrinsic student motivation. Students' desires to work on a particular project or to solve a chosen inventive problem were taken into account.
2. Equitable distribution of high and low academic performers. The average GPA of each team was a factor in distributing students among the teams. (USAFA only.)
3. Diversity of personality. Complementary MBTI and 6-hat scores were taken into account when forming teams [27-28,31].
4. Diversity of academic background. The majority of each senior-level team contained Mechanical Engineering majors. A variety of students from other majors also participated. These other majors (e.g., electrical engineering, biology, human factors, management) were distributed as evenly as possible, considering other factors such as student desire, and the project's unique requirements. Each team had at least one management major (USAFA) and usually one or more other students from other technical degree programs.

At USAFA, design teams worked on a variety of projects ranging from the Society of Automotive Engineers Formula Car Intercollegiate Competition to various smaller projects sponsored by the Air Force Research Laboratories (AFRL). Team sizes ranged from 12 (for the formula team) to 6 (for the smallest AFRL team). Half of these groups served as a "control" group, only using 6-3-5 for concept generation. These three teams included the SAE formula car, a project to design a "quiet" Baja-type vehicle, and a project to design an exercise machine for rehabilitating the walking gate of those with neuro-muscular diseases. The other three teams utilized the complete suite of six CG methods detailed in section 2. Two of these teams worked on different aspects of a project to enable UAVs to tag and track targets, while a third worked on the previously mentioned project to enable UAVs to perch.

At UT, design teams worked on an innovative sensor system for the oil field applications, a intelligence-surveillance-reconnaissance application for AFRL, and inventions for new products based on the students' life experiences. Five experimental teams, with five to eight members each, were formed from a multi-disciplinary senior design course with the industry sponsored projects. Seven additional experimental teams, with two members each, were formed from the freshman signature course.

Based on this team distribution, the experimental teams execute the suite of concept generation techniques (Figure 1), and the control groups execute an abbreviated set (such as a focus on the 6-3-5 method only). For example, in the modified 6-3-5 / CSketch method (6 people, 3 concepts, 5-15 minutes) structured brainstorming technique, each member sketches three solutions to a function or group of sub-functions within five to fifteen minutes. The concepts are then circulated to another member who modifies the original concept sketch within five to ten minutes. This rotation continues until each set of concepts has been modified or new, inspired concepts are drawn by every additional member. This can be accomplished with teams of less or greater than six, but six is the optimal number of team members for this technique.

Prior to applying the suite of techniques, team members complete a self-assessment of creativity based on a pre-survey [13-26,29-30]. In order to measure changes in an individual's creativity, we have chosen to use an established set of "creativity descriptors". Gough's [32] list of 18 descriptors has been evaluated across multiple fields using over 1700 subjects. These 18 adjectives have been shown to positively correlate to creativity (as measured by experts in the different fields). The list of descriptors is shown below in Table 2. Our assessment strategy entails asking the students to self-evaluate in these 18 areas both before and after they are exposed to the set of CG techniques described previously. As proposed in (Jensen, et al., 2009) [1], the difference between their before and after assessment in these 18 areas is a measure of their increase or decrease in creative ability. Both a control group and experimental group are used as described in detail in the results sections below.

Table 2. Gough's List of Creativity Descriptors

Capable	Egotistical	Informal	Interests wide	Reflective	Sexy
Clever	Humorous	Insightful	Inventive	Resourceful	Snobbish
Confident	Individualistic	Intelligent	Original	Self-confident	Unconventional

In addition to an assessment of creativity enhancement, the number of non-redundant, unique concepts generated by the control and experimental teams was recorded. This quantity measure provides an indication of the successfulness of the design teams to generate innovative solutions to their design problems. The quantity of concepts generated correlates with the novelty, diversity, and quality of the set of the concepts.

Analysis and Results

Tables 3 and 4 list the number of concepts generated by the different teams broken down by the different CG methods. Table 3 shows the results for the senior-level teams, where the first three teams are from USAFA and the latter five teams are from UT. Table 4 shows the results from the freshman signature course at UT. For each method, the teams had approximately 30-60 minutes of training on the use of the method followed by approximately 30-90 minutes of time to implement the method. Therefore, the use of the 6 methods represents about 3- 9 hours of total time.

Table 3. Number of Concepts for the Different Teams and CG Methods (Senior-Level Teams)

	Number of Concepts								
CG Technique	Team 1	Team 2	Team 3	Team 4	Team 5	Team 6	Team 7	Team 8	Avg.
6-3-5 + Morphological Analysis	16	3	**43**	**47**	25	**42**	**32**	12	28
Transformational Design +Mind Maps	23	1	10	25	**29**	30	18	20	20
Design by Analogy + Word Trees	**51**	10	17	10	11	15	12	**41**	21
Far Field Analogies	6	**25**	27	N/A	N/A	N/A	N/A	N/A	19
Historical Innovators	0	5	3	8	12	7	13	5	7
TIPS	0	27	0	0	5	7	4	3	6
TOTAL # OF CONCEPTS	**96**	**71**	**100**	**90**	**82**	**101**	**79**	**81**	**87.5**

Table 4. Number of Concepts for the Different Teams and CG Methods (Freshman-Level Teams)

	Number of Concepts							
CG Technique	Team 1	Team 2	Team 3	Team 4	Team 5	Team 6	Team 7	Avg.
6-3-5 + Morphological Analysis	**45**	**25**	12	5	**30**	15	**20**	22
Transformational Design +Mind Maps	10	5	**15**	**15**	6	**20**	15	12
Design by Analogy + Word Trees	0	0	2	0	4	0	4	1
Far Field Analogies	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Historical Innovators	3	0	4	3	4	2	0	2
TIPS	0	0	0	0	0	0	10	1
TOTAL # OF CONCEPTS	**58**	**30**	**33**	**23**	**44**	**37**	**49**	**39**

Table 3 shows that the average number of concepts generated by each senior-level "experimental" group through the use of the six CG methods is 88. As teams were instructed to only "count" concepts that were distinctly different from their other concepts, we believe this to be an extremely positive result. The three USAFA "control" teams, using only the 6-3-5 method, generated an average of approximately seven (7) concepts. Of course, this result is not directly comparable to the 88 concepts generated by the experimental group, as the control groups spent only a fraction of the time spent by the experimental teams on concept generation. However, a quantitative measurement can be developed noting that the experimental groups developed an average of 14.7 ([average of 88 concepts] / [6 CG methods]) new concepts per CG method while the control group developed only seven. This result is even more persuasive when one considers that fact that the experimental teams might tend to experience some "burn-out" of their creativity as they proceed through the suite of CG techniques. As shown from the table, the number of concepts generated generally decreases as one moves down a team's column in the table. This, we hypothesize, is due to the fact that, in general, the teams used the techniques in chronological sequence from the top row to the bottom row, or, alternatively, the teams selected the CG techniques that were most appealing to them. The table also shows the "top" producing CG methods (red numbers in the table) varied across the teams. This result might indicate that the team dynamics for each team or the type of design problem presented created different levels of productivity for each CG method. The use of multiple methods thus has an advantage of being able to access the unique strengths of the different teams/projects.

Table 4 shows the results of number of concepts per technique and the average number of concepts generated by the freshman invention teams. While it is clear that the smaller freshman teams (two members compared to an average of 5-6 members for the senior teams) generated a lower average (39 concepts), the results are encouraging and impressive. As with the senior teams, the number of concepts generated by the freshman teams per technique varied across the teams. It is also clear the freshman teams tended to concentrate on fewer techniques. This result might be explained by the quantity of domain knowledge and experience by the team members. Senior-level teams with greater domain knowledge may have been more willing to generate more concepts to fully wield this knowledge compared to the freshman. It is also likely that the senior-level teams had a different level of motivation to develop more concepts since their results were funded by external sponsors, whereas the freshman projects were self-generated projects to develop inventive products.

In addition to the exciting results related to the quantity of generated concepts, the design teams at USAFA and UT were surveyed regarding the self-assessment of creativity. Both control (used only the 6-3-5 CG method) and experimental (used a suite of CG Methods) groups were surveyed using the instrument shown in Figure 5. The students rated themselves for each of the 18 descriptors given, using the Likert scale provided (1 through 6). This assessment was conducted before the CG process and again after completion of all concept generation.

INSTRUCTIONS

For each of the 18 adjectives listed below,
rate yourself (fill in blue cells) using the (1-6) scale shown (green cells)

#	I am …	Rating	SCALE	
1	Capable			
2	Clever		1	Strongly Disagree
3	Confident		2	Disagree
4	Egotistical		3	Slightly Disagree
5	Humorous		4	Slightly Agree
6	Individualistic		5	Agree
7	Informal		6	Strongly Agree
8	Insightful			
9	Intelligent			
10	Interests Wide			
11	Inventive			
12	Original			
13	Reflective			
14	Resourceful			
15	Self-confident			
16	Sexy			
17	Snobbish			
18	Unconventional			

Figure 5. Creativity Measurement Instrument

Eighty-six (86) student surveys were recorded representing over 1500 data points (recall each survey used has 18 questions). Table 5 shows the results of the assessment. Note that the control group experienced an 8.2% increase while the experimental group experienced between 12.0 % and 17.2% increase as they progressed through the CG process. In this case, the USAFA experimental senior-level team members experienced an average of 13.6% increase, the UT senior-level team members experienced an average of a 12.0% increase, and the UT freshman team members experienced a 17.2% increase. These results show that the experimental groups had a 46% to 109% increase in their rating compared to the control group. Using Gaussian statistical analysis, a confidence interval is developed. The confidence interval provides a statistical answer to the question "how confident are we that the increase in creativity ratings for the control and experimental groups (8.2% vs. 12.0-17.2%) are really different". This question is relevant because these numbers are actually averages, with corresponding standard deviations, across a large student base. In this case, we are 85% to 99% confident that the 8.2% and the 12.0% and 17.2% are in fact statistically different, respectively. Thus, using the CG suite not only resulted in a large number of useful and innovative concepts, but actually improved the students' self-perception of their own creativity, which could possibly lead to lasting impact on their effectiveness as designers and engineers.

Table 5. Results of Creativity Assessment Process (All Teams)

Group	Increase in Creativity Rating (%) (from before to after the CG process)
Control (Did not Use CG Suite)	8.2
Experimental (Did Use CG Suite)	12.0 - 17.2
Percentage Increase for Experimental Group Compared to Control	46% - 110%
Confidential Interval for Experimental Group vs. Control Group	90% - 99%

Conclusions

Invention, innovation, and design are arguably at the core of the engineering education universe. This paper undertakes a study of innovation processes in engineering education through the development and assessment of a suite of concept generation techniques for engineering students. Building on a previous study, we advance the suite of techniques through the evolution and diversification of a technique known as historical innovators. This technique now includes principles from historical innovators demographically diverse in gender, race, engineering experiences, and era. Design teams using this evolved technique created inventions that were founded by the principles of individuals with which the teams identified and were inspired.

The suite of concept generation (CG) methods was then used by multiple teams of senior-level engineering design students and freshman multi-disciplinary students at both USAFA and UT. One purpose of this suite is to facilitate creation of a large number of innovative solutions to various design problems. In addition, the CG methods are intended to increase the creativity of the students who use them. These CG methods include two methods that are well known (6-3-5 and TIPS), two methods that have recently been reported in the engineering design and cognitive science literature (WordNet based Design by Analogy and Transformational Design Methodology) and two methods that have recently been reported in the engineering education literature (Historical Innovators and Far-Field Analogies). Assessment consisted of quantifying the number of concepts generated using the individual CG methods and also evaluating the increase in creativity of the students using these methods compared to those who did not use the suite of CG methods. The number of concepts per team, generated from the suite of CG methods, averaged 88 from across all methods and eight senior-level design teams (5-6 members per team). This result equates to 14.7 concepts per CG method. The control group used only the 6-3-5 method and generated approximately 7 concepts per team. Additionally, the increase in creativity for the group using the suite of CG methods was 46% - 109% greater than for the group that did not use the CG methods, advancing from an 8.2% increase to between 12.0 % and 17.2% increase. There is an 85-99% confidence interval in the difference between the percentage increases in creativity. These results, in addition to the pure quantity of generated concepts, are extremely encouraging for the future of engineering education to enhance creativity in students and focus on creating the next generation of inventors, innovators, and entrepreneurs.

Acknowledgements

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Appendix A

Historical Innovators Cognitive Generation Suite Resources [34-42]

Creativity & Innovation In Concept Generation

Marie Curie (1867 – 1934)

Discovered Radioactivity

Discovered Radium & Polonium elements

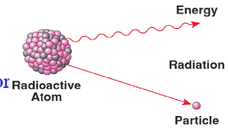
Two-time Nobel Prize recipient (Physics & Chemistry)

Characteristics:

- Revolutionary thinking and leadership for progress even in difficult conditions
- Leadership in education as first woman to hold position as Professor of Physics at Sorbonne
- Active promotion & enthusiasm for use of radium to alleviate suffering during World War I.

Principle: 1) Innovate and lead with your mind & heart even in the midst of difficult conditions

2) Methods of isolation/separation of residues in sufficient quantities can allow for its characterization & careful study of therapeutic properties



Application: Determine ways to isolate and characterize components to study and discover new uses

Creativity & Innovation In Concept Generation

Bette Nesmith Graham (1922 – 1980)

Inventor of liquid paper

Founder of multi-million dollar Liquid Paper company just years after the working as an executive secretary which was highest promotion for women

Creator of 2 foundations for women to support finding new ways to make a living

Characteristics:

- Seek alternate paths to professional success
- Community building and modeling examples bolster creativity & progress

Principle: 1) Connect actions of daily lives of people to meet their needs to get new ideas for solving your own problems

2) Constraints can be viewed as bolsters in ideation

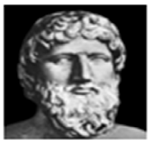
Application:

- Money is a tool not a solution
- Successful and widespread inventions can stem from small, homemade products

Creativity & Innovation in Concept Generation

Plato (428 – 348 B.C.)

Socrates – Plato – Aristotle – Alexander the Great



Characteristics:

- Beauty & truth of pure forms exist in all humans
- Socratic method (what do you mean, how do you know) externalizes in all forms
- Analogy of the

Principle:

1) Release your inner creativity

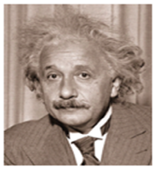
2) Pervasive curiosity related to pure forms

Application:

- Load information then disengage
- Constantly explore the perfect system

Creativity & Innovation in Concept Generation

Albert Einstein (1897 – 1955)



Published A Special Relativity (1905) Theory validated in 1919 during solar eclipse

Characteristics:

- Curiosity about all things (science, engineering, math, philosophy, & religion)
- Expressed confusion regarding physical relationships
- *Childlike, playful imagination*

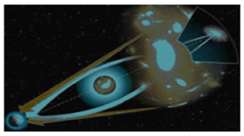
Principle:

1) Imagination of physical relationships

2) Combinatory play/ thought experiments

Application:

- Imagine, imagine, imagine
- Physical relationships, interactions, what ifs

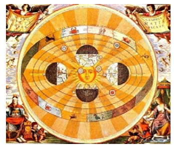


Creativity & Innovation in Concept Generation

Nicolai Copernicus (1475 – 1543)

Published Revolution of the Heavenly Spheres (1530)

Characteristics:
•Exhaustive researcher: Read everything in orbital mechanics
•Multidimensional: math, engineering, optics, law, military officer, & medicine
•Astronomy was his hobby
•Willing to question basic assumptions



Principle:
1) Question Assumptions
2) Hypothesize New Solutions
3) Methodically Test Hypothesis

Application:
•Identify Assumptions
•Propose New Solutions

Creativity & Innovation in Concept Generation

Christopher Columbus (1451 – 1506)
Explorer

Characteristics:
•Contradicts long-held conventional wisdom
•Developed skills needed to test his theories
•Gathered all available data & experience
•Excellent communication & able to get others on board
•Willing to forego comfort to pursue his ideas

Principle:
1) Extensive Customer Needs Analysis (Dialects)
2) Go Perpendicular – Take Risks

Application:
•Ask What Perpendicular Might Be For Your Project

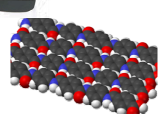
Creativity & Innovation In Concept Generation

Stephanie Kwolek (1923 –)

Inventor of Kevlar (stronger than steel & lightweight; used for protection and also in wide variety of sports equipment)
Recipient of 17 U.S. Patents & many national awards
Spearheads DuPont's polymer research
Characteristics:
•Joy, fun, and play can lead to important breakthroughs
•Teamwork is fundamental in design

Principle: 1) Recognize the unusual & break through the familiar
2) Use play to spark invention

Application:
• Play with objects & theories for new ideas
•(Re)consider familiarity to recognize the unusual
•Teams can create more and better ideas



Creativity & Innovation In Concept Generation

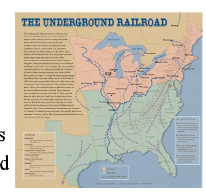
Harriet Tubman (1820 – 1913)

Known as the "Moses of her people"

Conductor of the *Underground Railroad* that guided hundreds of slaves to freedom in the face of danger even after she was free

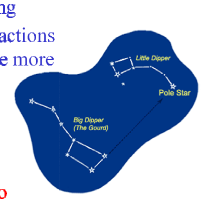
Connected astronomy and music to pass secret information about the Underground Railroad paths by singing "follow the drinking gourd" also known as the Big Dipper

Leader of abolitionist movement



Characteristics:
•All natural bodies seek freedom from constraints
•Communication comes in many forms
•Astronomy weaves across cultures and time

Principle: 1) Interdisciplinary connections are powerful & far reaching
2) Progressive ideas and actions for the greater good can be more important than individual accomplishment

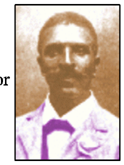


Application:
•Integrate disciplines for solutions
•Alternate, obscure, & contested routes to solving problems can be revolutionary

Creativity & Innovation In Concept Generation

George Washington Carver (1864 – 1943)

Agricultural Chemist
Discovered 300 uses for peanuts
Discovered hundreds of uses of soybeans, pecans, & sweet potatoes



Wrote 'Help For Hard Times' & other educational material for farmers to teach farmers to alternate soil-depleting cotton crops with soil-enriching crops (peanuts, sweet potatoes, & pecans)
Developed crop rotation method which revolutionized southern agriculture

Invented process for producing paints & stains from soybeans that earned him 3 different patents
Characteristics:

- Seek out economical ways to uniquely use agricultural resources & ways to conserve soil
- Intent on learning science, a willingness & determination to lead in education as the first Black college student & later first Black faculty member
- "He could have added fortune to fame, but caring for neither, he found happiness & honor in being helpful to the world." Epitaph on his grave

Principle:
1) Educate the customer with information/materials/products that directly & effectively applies to their needs
2) One crop (set of materials) can be reused/redesigned to yield many other products that can even be beneficial to the former crop

Application:
- "God gave them to me" he would say about his ideas, "How can I sell them to someone else?" The generalizability of his ideas made a meaningful impact on society.
- Use a negative byproduct(s) of a design as inspiration to redesign with preexisting materials & create positive outputs

Creativity & Innovation In Concept Generation

Charles Drew (1904 – 1950)

Discovered technique for storing of blood plasma (first blood bank)
Revolutionized medical profession by making it mobile (first huge impact during WWII)

1st Director of American Red Cross
Characteristics:

- When most Black men were segregated during WWII, his innovative ideas crossed races to save lives of any person thus is noted as a leader of the 20th century
- To fight segregation & the concept that biologically people are different based on race, he resigned his official posts after the armed forces rules that blood must be stored separately based on race

Principle:
1) By separating the liquid red blood cells from the near solid plasma and freezing the two separately, blood can be preserved & reconstituted at a later time
2) Consider mobility, ease of use, storage & distribution, states of matter, & societal impact as priorities in design process

Application:
- Prepare/ be forward thinking about emergencies or problems by designing ways to address them
- Inaction/absence in a process can speak as loud or louder than action not aligned with high priority principles

Appendix B

Historical Innovators in Student Design Projects

Historical Inventor: Zvi Yemini

A mechanical engineer trained at the Technion Israel Institute of Technology, with a masters in marketing from Baruch College, the 53-year-old Yemini started out designing massage showerheads and children's educational toys. His moment came when he designed an award-winning series of butterfly tool boxes for Home Depot. Then in 2002, Ehud Nagler had invented a water-powered engine, but couldn't figure out what to do with it. He brought the idea to Yemini, who came up with the idea for storing the engine in a hose reel.

Operating the reel is pretty simple: After using the hose, a flick on the well-marked lever on the side of the reel activates the winding process by using the power of the water flowing within the hose to haul the hose back inside. Because it relies on water power, the reel doesn't require batteries, electricity or springs to operate.

Zvi Yemini's design principles that are similar to our design

-The products ability to retract

- The winding process doesn't rely on much human capability, batteries, or electricity.

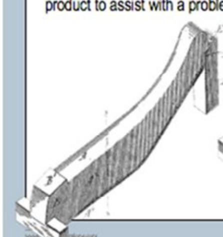
- Products ability to prevent tangling.

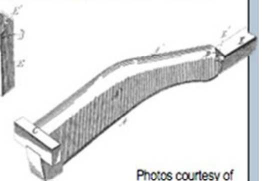
Historical Innovator

Sarah Boone was an African-American inventor who worked on the ironing board. Despite her tremendous effort, she actually did not patent the original idea for an ironing board. Rather, she saw there could have been room for improvement and strove to make the ironing board more functional, easier to use, and more in compliance with customer needs. On April 26, 1892, her final product was patented. The result? A slimmer, curvier ironing board which was specifically directed to improve on ironing sleeves and ladies' clothing. Below are her original designs – a top view and bottom view, respectively.

Sarah Boone's principles show various similarities to our design development:

- ❑Most evidently, her inventive problem was based on a clothing dilemma.
- ❑ She saw an already existing concept and worked to further improve it.
- ❑Her patented product can be used for a practical activity.
- ❑Both Sarah Boone's and our purpose was to design a product to assist with a problem widely suffered by our peers.





Photos courtesy of inventors.about.com

Historical Innovators

Karl Elsener helped inspire our project with the invention of the Swiss Army Knife in 1886.

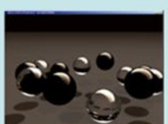
Frank Lloyd Wright also helped inspire our project through his persistnace in designing every part of his work - inclding his tools.

is the T² Model-Making Tool.

"An architect's most useful tools ~~are an eraser at the drafting board and a wrecking bar at the~~ site"
- Frank Lloyd Wright

Historical Innovator

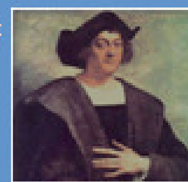
Nicoli Copernicus (1473-1543), was a Polish astronomer who hypothesized that the sun is the center of the universe as opposed to the popular belief of the time that the Earth was. This study triggered the beginning of the Scientific Revolution. Copernicus attended the Karkow Academy in Poland where he first began studying astronomy. His work focused on the study of spherical forms which lead to his publishing of the book "Revolution of the Heavenly Spheres." His studies also included mathematics, physics, law, and medicine.



Copernicus's principles can be related to our design in that they both involve the use of revolution and rotation. While in his case, the principles were applied at a much larger scale, specifically, on celestial bodies. Ours deals with the semi-circular rotation of rebounding mechanism. The current product with similar function to ours returns the ball to a single location, the free throw line. We questioned that bland design and hypothesized that it was possible to take it one step further, providing rebounds on a 180 degree axis..

Historical Innovator: Christopher Columbus

Biography and Characteristics:
- Contradicted long-held conventional wisdom by sailing West
- Developed skills needed to test his theories
- In search of more efficient route to end goal
- Gathered all available data & experience
- Willing to forego comfort to pursue his ideas
- Excellent communication & able to get others on board



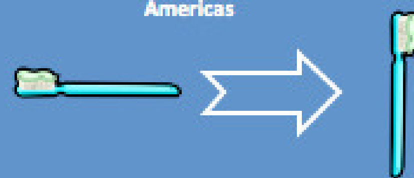
(1451 – 1506)

Italian Explorer of the Americas

Principles:

1) Extensive Customer Needs Analysis
2) Go Perpendicular – Take Risks

Applications to Toothbrush Device:



- Considered all of our available tools and ideas
- Compromised on favorite ideas for more practical/feasible ideas
- Asked for input of friends
- Learned idea generation concepts
- Original idea was to keep toothbrush from tipping over horizontally (Weeble wobble to keep bristles up)
- Thinking perpendicularly, we altered idea to keep toothbrush from tipping by staying vertical (Weeble wobble to keep entire toothbrush up)

Historical Innovator

Thomas Adams

- Experimented with "chicle" (Central American natural gum) in 1860's
- Developed a superior chewing gum, opened gum factory in 1870's
- Made first gumball machine in 1907
- Interesting/applicable concepts:
- Powered by gravitational and mechanical energy (no electrical energy needed)
- Load mass amounts of gumballs at a time in globe (at top of device)
- Gumballs drop one by one from storage area to bottom of device