AC 2010-1650: IMPROVISATION FOR ENGINEERING INNOVATION

Peter Ludovice, Georgia Institute of Technology

Pete Ludovice is an Associate Prof. of Chemical and and Biomolecular Engineering at the Georgia Institute of Technology. He received a B.S. and Ph.D. in chemical engineering from the University of Illinois and M.I.T. respectively. Pete carries out research on the molecular modeling of synthetic and biological macromolecules, and the use of humor and improvisation to improve technical innovation, communication and education. He works as a stand-up comedian in front of technical & non-technical audiences internationally. Pete hosts a weekly radio show entitled INSIDE THE BLACK BOX on WREK-Atlanta which uses humor to demystify science and technology. He also directs a Living Learning Community at Georgia Tech that uses humor to improve technical innovation, communication and education.

Lew Lefton, Georgia Institute of Technology

Lew Lefton is a faculty member in the School of Mathematics at Georgia Tech, where he is also the Director of Information Technology for the College of Sciences. He received a B.S. in Mathematics and Computer Science from the New Mexico Institute of Mining and Technology, and a Ph.D. in mathematics from the University of Illinois. Lew is an accomplished and experienced comedian who has done stand up and improv comedy for over 25 years. He is also involved in the community, where he directs a high school Improv comedy troupe called D.U.C.K., and leads a "geek" club at a local middle school called S.T.E.M.C.E.L.L. (Science, Technology, Engineering, Math Club to Encourage a Love of Learning).

Richard Catrambone, Georgia Institute of Technology

Richard Catrambone is a Professor in the School of Psychology at the Georgia Institute of Technology. He received a B.A. from Grinnell College and and a Ph.D. in experimental psychology from the University of Michigan. Richard is interested in the design of teaching and training materials--including software and multimedia environments--based on cognitive principles that help students learn basic tasks quickly and promote transfer to novel problems. In particular, he uses task analysis techniques to explore what students need to know in order to solve problems in a domain and then to use the results of the task analysis to guide the construction of teaching and training materials/environments.

Improvisation for Engineering Innovation

Abstract

Enhanced creativity among U.S. engineers and scientists is required in the face of strategic needs for innovation in numerous technical areas including: energy, the environment and health. NSF's third generation Engineering Research Centers explicitly require an educational component to enhance creativity to improve innovation. We have applied an approach to improving creativity that has traditionally not been used in technical innovation. The approach uses improvisational humor exercises to generate innovative ideas. The equivalence of humor and innovation is well established, and recently Sweeney and co-workers have systematically applied improvisation to enhance innovation. While this approach has been successful in non-technical fields, such as business and marketing, success has been limited in technical fields such as engineering. We have suggested a protocol based on a combination of humorous improvisation and stochastic molecular simulation to effectively search technical idea space. Humorous improvisation is the random idea generator for a stochastic search algorithm in innovation space; just as random number generators are used to sample molecular conformation space. We hypothesize that a more comprehensive refinement of idea space is required to make this approach effective for technical innovation. We have made some preliminary investigations of this protocol by carrying out workshops with undergraduate engineering design students. These preliminary results have suggested a basic protocol that uses a two-stage process: an improvised random idea which then inspires a technical problem solution. This two step approach is not used in Sweeney's approach, and may be responsible for its lack of effectiveness in technical areas, such as engineering.

Introduction

The importance of creativity was aptly described by Dr. Joseph Bordogna, Deputy Director and Chief Operating Officer of the National Science Foundation as "what societal progress… is all about," in a 2002 speech at the Rochester Institute of Technology.[1] Numerous others have extolled the importance of creativity, including the Editor in Chief of "Power Electronics Technology" who points out that Engineering Innovation requires creativity.[2] Given recent science and technology challenges for new enabling technologies in the fields of energy, health and the environment, it is generally agreed that creativity is of critical importance to produce this required technical innovation. Manifestations of this desire to produce more creative engineers and scientists abound. They include, for example, the recent announcement by the Korean Advanced Institute of Science and Technology (KAIST) that its new admissions policy will specifically include creativity as an admissions criterion in up to a fifth of the incoming freshman class.[3] This drive to produce creative engineers is also reflected in the focus of the Generation III Engineering Research Center (ERC) Program of the National Science Foundation. This program is designed to produce "engineering graduates who will be creative U.S. innovators in a globally competitive economy".[4] This program explicitly requires that ERC proposals address the educational requirements needed to produce creative engineers. According to a National Academy of Engineering study, increasing creativity in engineering may also help attract a more diverse demographic to the engineering field.[5]

Despite the aforementioned importance of creativity in engineering, there is no well established protocol to enhance or catalyze creativity in engineering design. Such a protocol must be developed before it can be incorporated into and optimized for engineering education. The work described herein is an attempt to do this. Regardless of the specific approach used, essentially all modern design theories depend on a point in the design process where a leap of creativity and innovation is required. This creative leap is not well characterized. Cross and Dorst have written extensively on the importance of the creative act in design theory.[6,7] Wang and Ilhan suggest that the creative act *is* essentially the act of design, but conclude that the "provenance of a creative act is essentially unpredictable in nature".[8] While design theories organize the knowledge and relevant design constraints so as to identify where and how this leap must occur, they do little to help induce or catalyze the creative leap.[9] Despite the attempt to systematically describe this creative act, documenting the stages of the creative process is not equivalent to understanding the origin of creativity.[10] Improving this creative skill is a national priority in science, engineering and math. A committee from the National Science board met in August of 2009 to recommend policy to produce talented math and science students that also posses the hard-to-define skill: the ability to innovate.[11] Improving design methodology without addressing this critically important creative step is tantamount to the same flaw that exists in the Six Sigma approach currently. The Six Sigma approach to quality improvement uses statistical analysis to characterize a quality issue and the DMAIC process to organize resources to address this problem. However it often neglects the actual formulation of the solution to the problem, which is typically the rate limiting step. For this reason, many managers are frustrated at the lack of progress on a problem despite their best efforts to install the Six Sigma process because Six Sigma in no way addresses the critically important creativity step.

True creativity requires that innovators increase their creative energy and allow this energy to help sufficiently sample idea space. We propose a mechanism to increase and focus creative energy specifically for scientists and engineers. Despite their aversion to creative energy, scientists and engineers do understand the sampling of other variable spaces with various algorithms. For centuries, scientists and engineers have understood how to manipulate thermal energy to efficiently move through the state space of both ancient and modern materials. The principal of annealing metals has been understood for thousands of years and simply involves a local increase in thermal energy (heating) to allow the packing of the metal atoms to find a state that has better material properties. Finding the optimal amount of thermal energy is the key. Too little thermal energy or heat and the material will not change, but too much thermal energy will simply melt the material and not allow it to settle into a lower energy state that typically produces superior properties. Similarly, computer simulations are also used to sample the state of materials to understand structure-property relationships and design new materials. The key to an effective simulation is the sampling algorithm. Narrow sampling and the simulation will not move from the initial state of the material, but sampling that is too broad and the material will end up in a physically unrealistic high-energy structure. Physicist M. Mitchell Waldrop recognized that creativity works exactly the same way in the book "Complexity: The Emerging Science at the Edge of Order and Chaos".[12] Waldrop claims that the edge of chaos is where the components of a system never quite lock into place, and yet never quite dissolve into turbulence either. This chaotic region is where an infusion of creativity energy creates just enough chaos to efficiently sample idea space but not so much that the ideas generated are totally unreasonable.

The analogy between temperature in annealed materials and creative energy in innovation is a simple logical concept that we plan to exploit in improving creativity in engineering. In annealing, it is thermal energy that samples the states of the metal. In stochastic simulation, it is fluctuations in energy that sample the state of the simulated material. The creative energy that allows the sampling of idea space is humor. The equivalence of humor and innovation is well established. Edward de Bono points out that both humor and innovation require lateral thinking that jumps from one plane of thought to another. This transfer is the punch-line in a joke where two disparate ideas are compared in a humorous way. In innovation, this transfer is seeing a problem in one domain from the perspective of another.[13] Arthur Koestler formulated this in terms of bisociation theory, where both humor and innovation occur via the associative thinking that discovers the intersection between two disparate planes of thought or idea space.[14] The concept of bisociation is illustrated for both humor and technical innovation in Figure 1. Intersecting planes represent the two disparate domains of thought, and the curve is the improvisational path that will sample the intersection of these planes. Many of the points on the intersection represent ideas that will not be filtered or refined into a useful design solution (open circles in Figure 1b). However, some will produce useful innovative ideas (filled circles) such as the plastic-metal laminate film commonly used in food packaging.
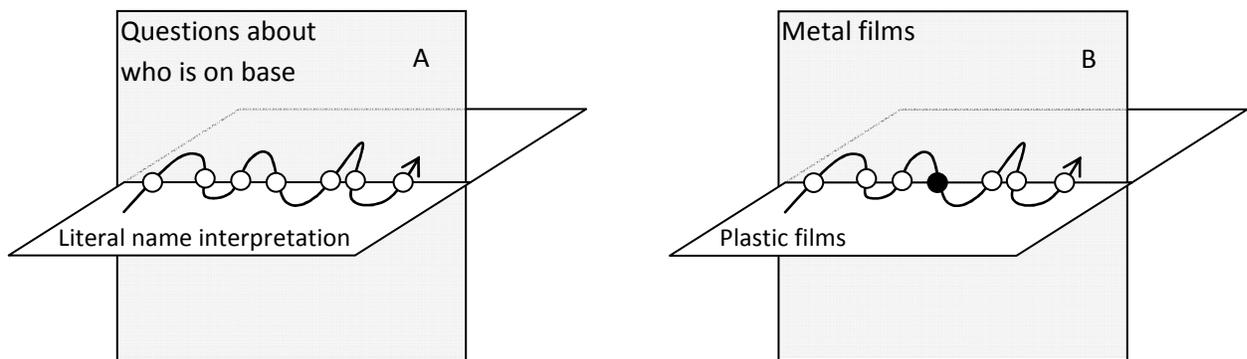
FIGURE 1. Schematic of Koestler's Bisociation Theory applied to a joke (A) and a technical problem (B). The left diagram depicts the classic "Who's on First" gag of Abbott and Costello where each open circle represents an individual joke. The right diagram explores the common application of plastic and metal films. Each circle on the right represents various ways of combining metal and plastics. Most of these are impractical given the large difference in the melting point of these materials. The filled circle on the right represents a feasible solution in the form of plastic metal laminates that combine the good barrier properties of metal films with the ease with which plastic films can be sealed. These are commonly used in modern packaging

Given this equivalence of humor and innovation, we hypothesize that a humorous environment is required for effective innovation. Humor is the energy used to sample idea space, and below we describe a method to harness this humorous energy to catalyze the creative step in engineering design. While using humor appears to be amethodical or lacking in a method, such amethodical methods are somewhat common in computer programming.[15] In fact, improvisation is currently being used to improve computer program algorithm design at Georgia Tech among undergraduates.[16] Since this method addresses the creative step in engineering design, it will typically be used as part of an engineering design protocol as mentioned above. To illustrate this, we describe its potential use with a common approach to innovative engineering design know as

TRIZ.[17,18] This systematic design approach takes its name from the westernized acronym of the Russian name (Тероия решешия изобретательсҹих задач) which translates as "The theory of inventor's problem solving". This method uses tools and design heuristics to systematically innovate. It is based on a number of basic principles or laws including the principle of "Technical Contradiction". The technical invention is broken down into its internal contradictions (i.e. faster vehicles require larger engines which add wait and make vehicles slower). These technical contradictions are resolved using a systematic set of steps. However, TRIZ offers no means to improve creativity during the execution of any of these steps, and the proposed approach can be used generally within TRIZ or other systematic approaches to improve their overall effectiveness.

The most obvious incarnation of humor as a means to sample idea space is improvisational comedy. Popularized by improvisational troupes such as "Second City" in Chicago and television shows such as "Whose Line Is It Anyway," this technique uses improvisation to guide performers through a humorous skit. This approach has been applied effectively to generating ideas for business and other non-technical organizations by simply focusing on business, organizational or training ideas vs. comedy skit ideas.[19,20] Our hypothesis is that such techniques, can be adapted to generate engineering design ideas. Currently the most popular and successful approach is that of John Sweeney, founder of the Brave New Workshop (BNW) improvisation troupe of Minneapolis[20] because of the clarity of this approach and the recent success it has achieved. Sweeney's approach employs two steps: an idea generation step, followed by a filtration step that focuses on the more feasible ideas. Recent articles have implied that this approach can be applied to engineering.[21,22] However, Julia Schmidt, the former president of the Brave New Workshop, states that this method does not necessarily work for filtering technical ideas in the statement below.

> "…we are GREAT at helping clients with two things: 1) generating a lot of ideas at the TOP of the brainstorming funnel (we are NOT really suited to help technical teams further refine and develop ideas, as we are based in improvisation not engineering) and more generally, 2) BEHAVIORAL change—we help individuals and teams shift their own behaviors that affect the culture of innovation (or lack thereof) within their organization."
>
> Julia Schmidt
> Former President, Brave New
> Workshop[23]

We contend that the failure of improvisational techniques in the technical realm of science and engineering is due to specific differences between sampling technical idea space and more general idea space associated with marketing, advertising and business. By addressing these differences we are developing a method for sampling technical idea space that is currently being tested and refined.

A Method for Technical Innovation Using Improvisation

A basic assumption of our approach is that Sweeney's method fails because of the unfocused idea filtration scheme that is used. Sweeney uses improvisational exercises to produce ideas and then filters them later. This general filtration scheme works fine if the goal is to produce ideas for advertising and marketing, because these ideas are general in nature. This means that most

ideas produced from improvisation exercises are of similar usefulness for marketing or advertising. However, technical solutions are much more constrained, and require a more extensive filtration of the improvised results because they are farther from the original idea in idea space as seen in Figure 2. In general, a random idea might be relatively close to a marketing idea such as a humorous idea for a television commercial. Neither of these ideas is bound by physical constraints. However, technical ideas to address technical problems are constrained by numerous physical, chemical and thermodynamic laws. For example, the random idea of a talking animal produced from an improvisation exercise may be a perfectly good idea for a business marketing campaign or commercial, but would provide little insight into the solution to a technical problem. However, such a random idea might inspire a useful technical solution.
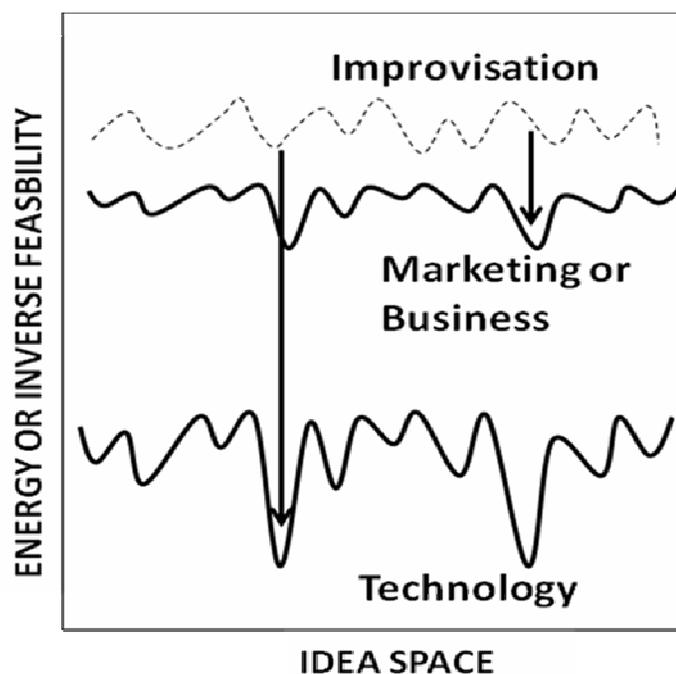
FIGURE 2. Schematic differences in the refinement of random ideas generated from improvisation for both general and technical applications. The larger difference between random ideas and feasible technical ideas suggests the need for an additional component of refinement for technical innovation due to the increased physical, chemical and thermodynamic constraints on technical ideas.

Some insight into the different sampling of idea space seen in Figure 2 can be obtained from the sampling of molecular conformation space in the simulation of molecular structures. Improvisation is the equivalent of randomly sampling conformation space of a molecule. Such algorithms are commonly used on commercial molecular modeling software such as MOE[24] and CERIUS2[25] to look for interesting conformations for a particular molecule. Such algorithms can be used to see if it is possible for a molecule to adopt extended, compact, helical or straight conformations, but none of these conformations are tested for feasibility. Neither of these sampling methods are completely lacking in constraints. For example, while the torsion angles, about which covalent bonds can rotate, are freely sampled, the bond lengths and bond angles undergo minimal perturbations. Similarly, improvisation is constrained by the basic syntax of language and the basic structure of the improvisation exercise.
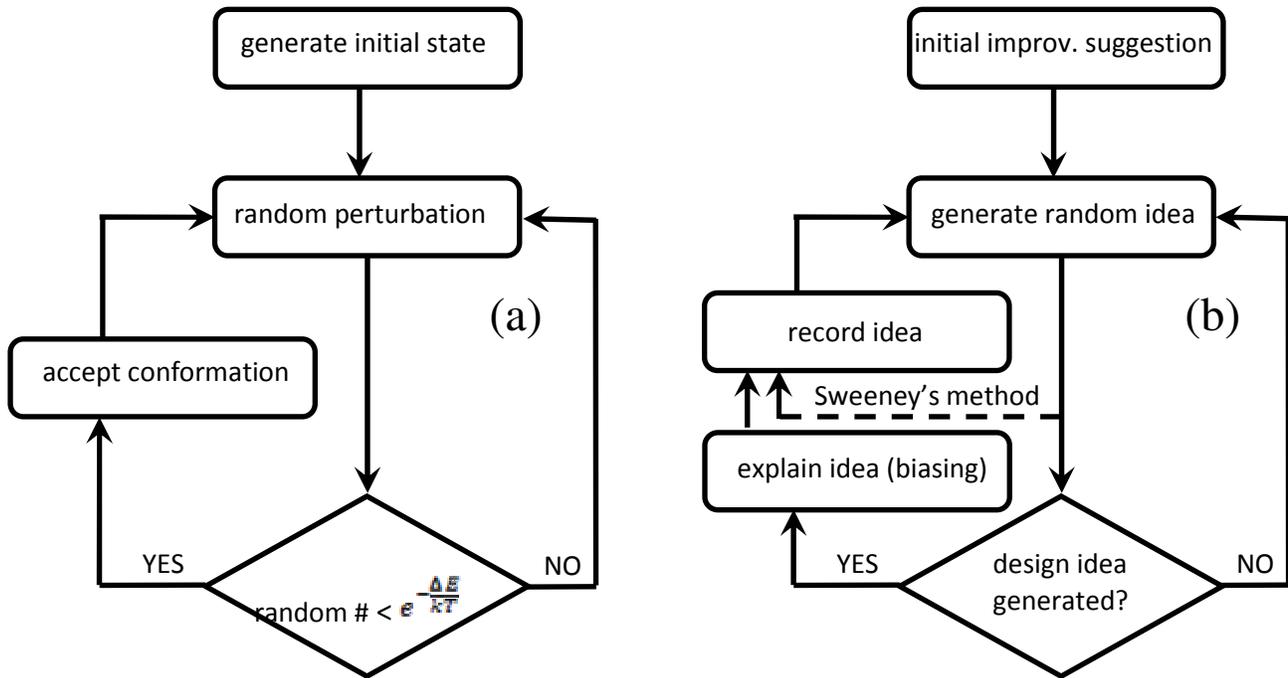
The use of improvisation to generate general business or marketing ideas is similar to the same random searching of molecular conformations followed by a minimization of the molecular conformation energy. This energy minimization allows the random idea to crystallize into a more feasible idea. However, minimization will only converge to a low energy structure in the vicinity of the starting point for a highly dimensional conformation space. Similarly, the direct generation of applied ideas and solutions from random improvisation ideas only results in solutions that are closely related to the improvisation ideas. A more rigorous search method such as molecular dynamics, stochastic dynamics or Monte Carlo simulation is required to find lower energy minima that are farther from the starting point. Therefore we assume that one or more additional improvisation steps are required to produce technical solutions from random ideas derived from improvisation. This additional step or steps helps to traverse the additional distance in idea space as seen in Figure 2. Therefore, we will assume that these additional steps are required to apply improvisation to technical innovation and that these steps must be carried out by personnel with technical backgrounds. Failure to address these two requirements is likely responsible for the failure of traditional approaches like those of Sweeney and co-workers to address technical innovation.

Unlike the direct optimization following a random search, most stochastic molecular simulation algorithms do not execute the random conformational search and the energy minimization independently. Typically, the last energy minimized structure is used as the starting point for the next random conformational structure. Therefore, when low energy structures (or high feasibility in idea space) are obtained, the subsequent conformations are biased to reflect the characteristics of these low energy conformations. This biasing is of critical importance for the most commonly used stochastic sampling algorithm. This algorithm, the Metropolis Monte Carlo (MMC) simulation algorithm, is very efficient at sampling complex variable spaces.[26] The breakthrough that Metropolis made over traditional stochastic or Monte Carlo methods is the elimination of the transition state matrix. In these traditional approaches, searching variable space proceeds according to the known probability of transitioning from one state to another. These transition states are very difficult to calculate for physical systems and impossible to know for searching creative idea space. The MMC approach searches variable space by making a random change or perturbation of the state, and then accepts this random change according to a biasing distribution that is guaranteed to produce a system with the appropriate state distribution based on physical constraints of the problem. Since improvisational exercises are designed to produce random perturbations in idea space they will work well in the framework of the Metropolis Monte Carlo method. It is the failure of Sweeney to include this biasing during the search process that fails to focus the random perturbations from improvisation on a constrained engineering design problem. Therefore we testing ways to implement such biasing and eventually plan to test the following hypothesis.

HYPOTHESIS 1: The efficiency of sampling engineering idea space is increased by applying a bias during the search of idea space.

This hypothesis will eventually be tested by comparing the results of improvisational exercises with and without biasing under the same conditions. In the meantime we are simply testing various methods to apply a multistep approach to produce technical solutions from ideas produced by improvisation exercises and explore best practices for these innovation exercises. Specifically, our initial results focus on the means by which a random improvised idea can

produce a solution to a technical problem. Later, we plan to integrate technical solutions into the improvisation process to produce the idea space biasing that is currently used in molecular simulations.

Figure 3. Schematic representation of the traditional Metropolis Monte Carlo algorithm for (a) a physical simulation and (b) an improvisation to generate technical engineering solutions.

Figure 3 provides a side-by side comparison of the Metropolis Monte Carlo algorithm applied to a typical physical simulation and to the proposed search of idea space. The example physical system is the simulation of a physical system at constant temperature. For the sake of illustration, assume the physical system used in the traditional Metropolis Monte Carlo algorithm in Figure 3 is a periodic cell of liquid water. The initial state at the top of this schematic could typically be a periodic cell containing randomly placed water molecules at the density of water. The random perturbation is simply a random translation and/or rotation of one or more water molecules. The biasing test (contained in the diamond shape in Figure 3a) assures that the system follows the constraints of statistical mechanics for constant temperature system. In such a system, statistical mechanics clearly defines the probability P of any given state which is given by Equation 1.

$$P \propto e^{-\frac{E}{kT}}$$

[1]

This probability P is proportional to an expression commonly called the Boltzmann factor, where E is the current energy of the system, k is Boltzmann's constant and T is the absolute temperature. By using the change in the energy (ΔE) associated with the system perturbation in the Metropolis Monte Carlo algorithm, Metropolis showed that this algorithm would eventually converge to the probability distribution in Equation 1. As seen in Figure 3, a uniform random number between 0 and 1 is chosen and compared to this Boltzmann factor using the change in energy between the current and previous state. If the change in energy is negative then this

exponential factor is always greater than 1, so the new state is always accepted. If the change in energy is positive it is only accepted based on the Boltzmann probability. Applying this approach over and over results in a low energy state that has the Boltzmann distribution superposed on top of that low energy state.

The temperature (T) plays an important role in this algorithm, and the equivalent quantity in the improvisational search of idea space (Figure 3b) is humor. Temperature or humor provides the energy that creates the near-chaos described above by Waldrop. As the temperature approaches infinity, the exponential factor approaches one and essentially all randomly perturbed states are accepted. This is the turbulent state the Waldrop describes. As the temperature approaches zero, then only random perturbations that reduce the energy are accepted. This results in a systematic search for a local minimum that produces this state that Waldrop refers to as "Locked into place". Neither of these two extremes is efficient for sampling molecular conformation space or technical idea space. The high temperature case produces only high energy structures that are unrealistic, whereas the low temperature case produces only one local minimum and does not sample state space well. There exists an optimal temperature for physical simulation and an optimal humor level for searching of idea space.

Figure 3b is only a general schematic of the proposed approach to applying the Monte Carlo Metropolis stochastic simulation to the sampling of technical idea space. Details of the optimal approach will likely differ, given that statistical mechanics provides no guidance on the biasing of the idea space probability distribution as it does for molecular conformation space as seen in Figure 3a. While improvisation provides an effective random idea generator, how to use such ideas to generate potential technical solutions and bias further idea-space exploration in the direction of such solutions is not currently known. The statement above from Julia Schmidt reflects the failure of Sweeney and co-workers to go beyond this initial random idea generator phase and this fact is responsible for their difficulty in applying their method to technical innovation. The research program described herein focuses on exploring methods to use randomly generated ideas from traditional improvisational exercises to generate potential technical solutions and bias subsequent ideas in the direction of feasible technical solutions as seen in Figure 3b.

The initial improvisational suggestion at the top of Figure 3b may be technically related or a random suggestion from someone participating in the improvisational search of technical idea space. Such random suggestions, from improvisational show audience members, are a common way to start improvisational performances. The subsequent generation of a random idea utilizes standard improvisational exercises.[27] Next, the random idea generated from the improvisational exercise must be used to generate a solution to a technical or engineering design problem. Our initial approach to this stage is to simply use random improvised ideas to inspire technical engineering solutions. Sometimes a solution is inspired and sometimes not. However, this is the current form of biasing used in the preliminary work below. However, we have not designed an effective way to use a particular technical design solution as a new starting point, thereby allowing an iterative search that converges on a class of technical solutions. This biasing may require improvisation completely inside technical idea space, but so far we have had little or no positive results with this approach (see preliminary work below). However, we are hopeful that simply exposing the technical ideas in the course of this two stage improvisation process may

eventually illustrate how these may be incorporated into an iterative Metropolis Monte Carlo process.

The application of humor to technical innovation is not new, but has not been studied in the systematic manner that is proposed. The proposed work will help overcome the aversion to such a non-traditional approach that has the potential to drastically improve technical innovation. Humor in the workplace is generally regarded as a positive thing because it appears to have positive effects such as relieving stress, but more recently it is associated with greater creativity.[28,29] The Kodak Corporation has created a humor room where employees can go to relax or have creative brainstorming sessions. The Kodak Humor Room offers joke books, cartoons, video tapes of comedians, stress-reducing toys and software for creative problem-solving. Solvay Advanced Polymers, which has created an innovation space (the Think Loft, see Figure 4) similar to the Kodak's Humor Room, is one of our local collaborators on this work. Hoechst Celanese maintained a similar room at its former research and development facility in South Carolina that was actually triangular in shape.[30] Unlike the Kodak Humor Room, which was used mainly by non-technical personnel, the equivalent rooms at Solvay Advanced Polymers and Hoechst Celanese were sometimes used by technical personnel.

Despite the apparent success of the Kodak humor room, a significant culture barrier still remains. The technical advisor on the Humor Room project was Lindsey Collier, now the owner of Creative Edge Associates in West Henrietta, New York. Despite the success of this project, Collier points out that many Kodak managers believed this approach was inappropriate and resisted promoting it in the company newsletter and secretly hoped it would disappear, despite its very positive publicity in external print and TV. This attitude among some Kodak managers is consistent with the perception that people generally associate true creativity with people in the arts as opposed to engineering.[31] A study comparing the creativity of music and engineering students concluded that, while music students were statistically more artistically creative than engineering students, there was no statistical difference between the measured scientific creativity levels of

Figure 4. The Think Loft at Solvay Advanced Polymers in Alpharetta, GA.

these same students.[32] The above study on people in the arts and engineering examined the hypothesis that creativity is not valued in modern engineering education.[31] This study concluded that engineering education does not embrace many of the open-ended non-traditional principles commonly associated with innovation such as: keeping an open mind, learning to fail and encouraging risk. Another principle that was not typically followed by engineers in this study was the search for multiple answers. A similar study we carried out previously on collaborative learning found that collaboration was stifled by the engineering students' perception that engineering problems have only one answer.[33]

Innovation often takes many years to produce practical successes. Because the application of humor to technical innovation, as seen in the aforementioned Kodak, Solvay and Hoechst Celanese examples, is a relatively recent phenomenon, it is difficult to find a successful example of humor being used in technical innovation. However, just because humor was not purposely introduced to an engineering or science environment does not mean that it did not exist there. We contend that humor may have been partly responsible for one of the greatest historical examples of technical innovation in the history of the U.S., the Lockheed Martin Skunk Works. This aerospace engineering think tank produced some of the most innovative aviation designs in history in very short periods of time. It took its name from the tendency of its members to answer the phone "Hello, Skonk Works," (from the backwoods still in the L'il Abner Cartoon) in recognition of the smell from the nearby vinyl plant.[34] Later, because of the copyright issue with the cartoon, it was changed to Skunk Works. The founder of the Skunk Works, Clarence "Kelly" Johnson, eliminated all unnecessary paperwork. This fact coupled with working on high pressure top secret projects created a culture of ambiguity. Ambiguity is also one of the important innovation principles discussed in the aforementioned study on engineering education.[31] However, ambiguity has also been known to give rise to spontaneous humor as a way of coping with the ambiguity, which often defies characterization by normal language.[35] We suggest that the design successes from the Skunk Works may be partly due to the humor that accidentally arose from the ambiguous nature of this very innovative organization.

In addition to a cultural barrier to the use of humor in improving innovation, there may a general bias among scientists to the application of creative exercises in general. A 1984 study by Lawson comparing designers and scientists found that scientists tended to use fundamental knowledge to systematically implement designs.[36] In contrast, designers initially explore multiple solutions – scientists are problem-focused whereas designers are solution focused. While engineering design specialists contend that this creative exercise is important, they limit it to a brief discussion of "Brainstorming" and concentrate more on the systematic approach to refining engineering ideas.[37] Given the cultural change that may be required to see this method utilized for engineering design, we are testing it in academic classrooms first. Perhaps the establishment of a well designed educational program in this area can help start the cultural change that may be required to see it introduced into industry. The results of testing this protocol in two engineering design courses at the Georgia Institute of Technology in 2008 and 2009 are described below.

Preliminary Results

While we eventually plan to test the aforementioned hypothesis, many trials will be required initially to determine the best practices for this approach. The first two trial exercises were carried out by P. Ludovice and L. Lefton with engineering students at the Georgia Institute of Technology under an Institute Review Board approved protocol for human subjects research (protocol number H08340) which allows us to analyze surveys and taped observations from these sessions, as long as they are done so without using participant identities. In addition to their faculty positions at the Georgia Institute of Technology they both have experience in stand-up and improvisational comedy. While these qualifications are important for the development and testing of this protocol, it will remain to be seen if this protocol can be transferred to technical personnel that do not have significant improvisation experience.

Table I. 2^2 Factorial Design mixing technical and humorous components in the "Shopping List" short form improvisation.

| Random Humorous Story Random Shopping List from audience	Random Humorous Story Project Design Component List
Story Focused on Design Task Random Shopping List from audience	Story Focused on Design Task Project Design Component List

The first exercise tested an approach to mixing improvisation directly with an engineering design problem with 16 students from a sophomore-level mechanical engineering robotics design class at Georgia Tech in the Fall, 2008 semester (ME2110). This exercise simply tested if technical concepts could be easily mixed with improvisational exercises. In this exercise we explored the robotics design problem for that particular course using an improvisation exercise commonly known as "Shopping List". This exercise involves improvising a scene where a moderator occasionally yells out a random item that the improvisers must incorporate into the improvised scene. The course-defined design task (what the robotic device must do) and the list of materials provided to build the assigned robotic device (actuators, stepping motors and other mechanical devices), were provided by the instructor. The creativity workshop began with a short briefing about improvisation and approximately 30 minutes of simple warm-up exercises. Experience has shown that these warm-up exercises are critically important for getting participants in the appropriate mental state.[27] The shopping list began in the traditional state and then the aforementioned task and list of materials were mixed in to create 4 possible improvisation scenarios. These consist of alternating the theme of the improvisation between a typical funny suggestion and the theme of the robotic design and alternating the shopping list items between a funny random list and the components to be used in the robotic design in the 2^2 factorial design seen in Table I. While only 8 students completed the survey we did learn some useful, qualitative information from this exercise, namely that the students appear to enjoy this general approach.

The post-exercise survey was designed by R. Catrambone, an educational psychologist, and Professor of Psychology at Georgia Tech. The survey questions were rated from 1(strongly disagree) to 5 (strongly agree). In addition to some open-ended comment type questions the survey questions included:

1. Have you ever **seen** improvisational comedy before?
2. Have you ever **done** improvisational comedy before?
3. The exercises done in this improvisational session made me feel uncomfortable.
4. The exercises done in this improvisational session were fun.
5. The exercises done in this improvisational session stimulated my creativity.
6. The exercises done in this improvisational session might potentially help produce useful ideas for our classes design project.
7. I consider myself a creative person.
8. I consider myself a funny person.
9. I consider creativity just as importance as technical expertise in engineering design.

10. I think more creativity exercises like this one could benefit this course and similar engineering design courses.

The mean values of the survey are seen in Figure 5 with their 95% confidence limits. Only questions 4, 9 and 10 were statistically different from the neutral answer of 3 (partially agree, partially disagree). The strong positive response to question 9 is encouraging with regard to perceived importance of creativity. If our assumption that humor is critically important is correct then there should be a positive correlation between question 4 and question 10. A linear regression fit of the numerical response of question 10 to question 4 (Q10=A×Q4) produced a correlation coefficient of A=1.008±0.137 at the 95% confidence level. This positive correlation, while based on a small sample, is consistent with assumption that humor is of critical importance.
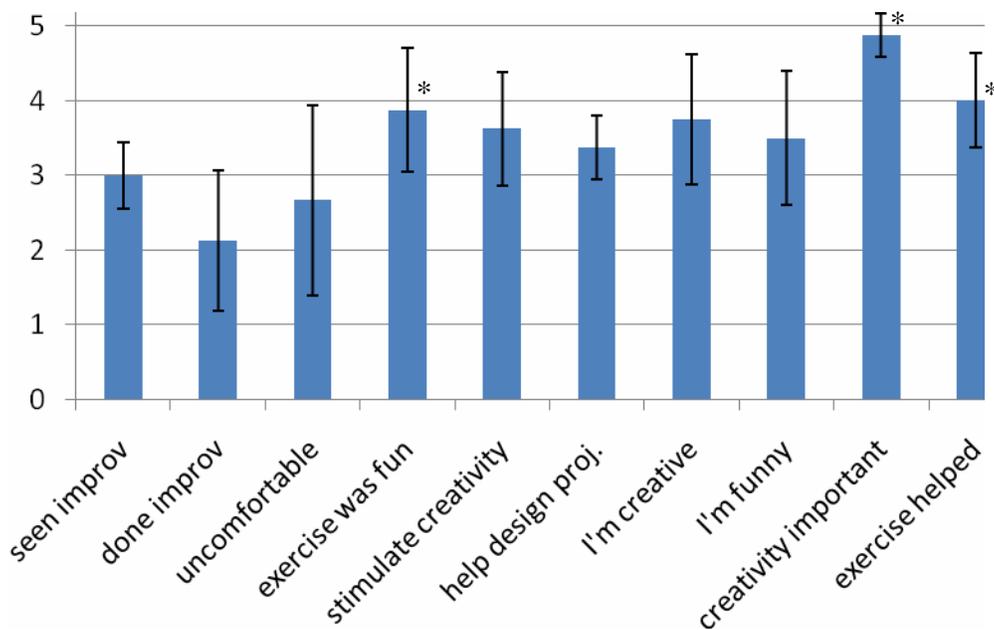
FIGURE 5. Results of survey questions in creativity workshop for a mechanical engineering robotic design course (ME2110). The error bars are the 95% confidence intervals about the mean and an * indicates that the mean is statistically different from the neutral answer of 3 at the 95% confidence level.

Observation of the session indicated that the mixing of technical design goals and humor-induced random ideas was relatively awkward using the factorial approach seen in Table I. The mixing of these concepts seemed to constrain the humor-based random idea generator. This made the ideas non-random. Further, the mixing of the two did not spontaneously produce design ideas. Students commented that we would "Drift" from the design problem. This suggested that humorous improvisation should be used as a truly random idea generator independent of the design problem, and then these ideas could be used to seed an approach to the engineering design problem. If the random idea generates a viable approach to the engineering problem it is collected, as seen in Figure 3b. This is a simple form of the biasing used in the Metropolis Monte Carl method. If a technical engineering solution is produced then the original

random idea is eventually discarded as in the MC method. The creation of the technical idea during the improvisation session also plants a seed of a particular technical bias in the minds of the improvisers. These seeds represent the bias toward more feasible solutions. While it is possible that such seeds many never take hold, we suspect that they will be based on observations of humorous improvisation. In long form improvisation, an early idea is often revisited later in the improvisation. This is a natural tendency of both improvisation and stand-up comedians and is referred to as a "Call-back". We are hopeful that a similar phenomenon will occur in these innovation exercises. This exercise motivated this biasing approach which was used in the second exercise below.

In a second exercise in the Fall Semester of 2009, twenty-two students in a chemical engineering product design course at Georgia Tech participated in a similar exercise. After warm-up exercises, different improvisation exercises were used to generate random ideas. These included "Slide Show", which starts with some random suggested places, and a single narrator who narrates a slide show of a trip to these places comprised of several participants making random periodic poses. Another exercise that requires the improviser to describe an alternate use of a random prop was also employed. After narration from the "Slide show" or the alternate description of the prop is complete, another participant describes a potential solution to a posed problem based on the idea produced from this narration. This was a chemical product design course (CHBE4535), and the example tested was a shoe deodorizing product.

Open feedback on the questionnaire appeared to indicate this "Slide Show" approach was perceived as more effective for innovation by the students. That perception may be because this was the only improvisation approach used where sufficient time was available to derive engineering solutions from the random improvised ideas. Students responded very positively to extraction of ideas from the "Slide Show" exercise. The lack of response from the props game was likely due to the lack of converting these ideas into actual engineering designs. However, one survey indicated that the students were concerned that the props game is more likely to result in embarrassing ideas by the students, whereas any embarrassment is shared in the "Slide Show" game. This underscores the importance of having an experienced facilitator (who narrated the slide show poses in this case). A comment during the exercise and on the survey also stressed the importance of experienced facilitators and the warm-up exercises to provide the appropriate mental states. The students also commented that the theory behind these exercises was of little importance and they just wanted to jump into the exercise.

Open comments on the survey clearly indicated (8 of 22 positive responses) that the students were most encouraged by the development of engineering design ideas from the random improvised ideas. An example of such a generation is seen in the generation of the idea "going to the bathroom" from the slide show narration. The person recording these improvised ideas and generating design ideas for the shoe deodorizer connected this idea with the reed diffusers placed in containers of fragrant oils in home bathrooms. This then suggested the idea of using capillary channels in the deodorizing shoe insole to distribute deodorizing chemicals throughout the shoe. Such a design approach may also redistribute order-causing perspiration in the deodorizing insole. This illustrates the use of a random idea to generate a potentially viable design idea.

Figure 6 illustrates that, unlike the previous test, students believed that this exercise may potentially help them with their design project (the average answer for question 6 is statistically different from the neutral answer of 3). This occurred despite the fact that there was not statistical difference between the attributes of the second and the first. While only significant to the 90% confidence level, the only statistically significant difference between these two studies was in question 6 regarding the usefulness of this exercise for the design project. This likely occurred because only the second study was able to produce suggestions for the specific design project. Our initial qualitative assessment is that a two stage process in which the technical problem constraints are added subsequent to an initial random idea generation may be superior to mixing these technical constraints in the initial step.
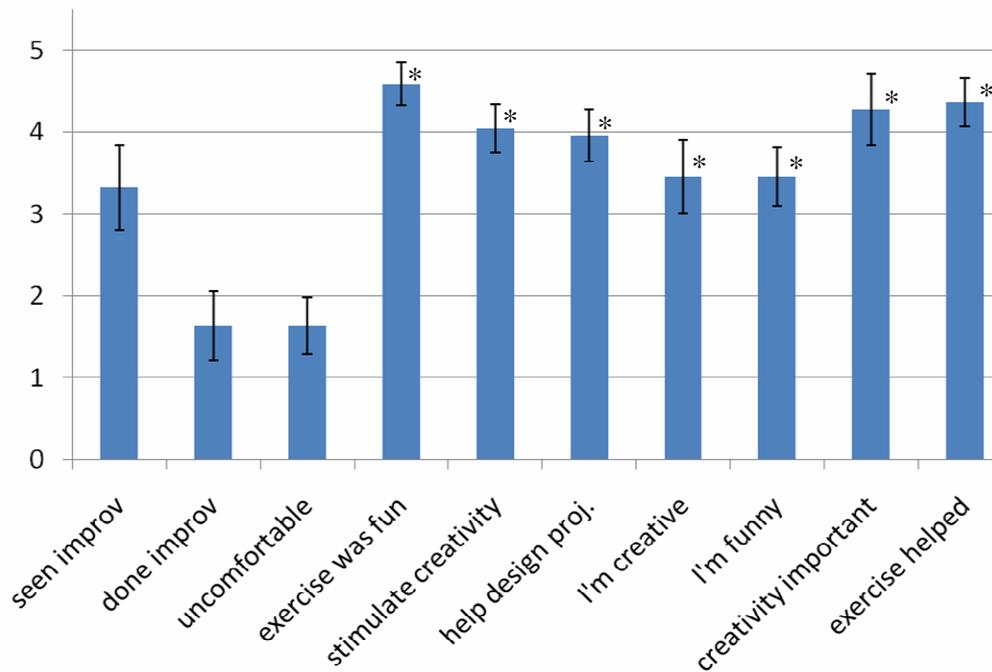
FIGURE 6. Results of survey questions in creativity workshop for CHBE4535. The error bars at the 95% confidence intervals about the mean and an * indicates that the mean is statistically different from the neutral answer of 3 at the 95% confidence level.

A subsequent workshop, carried out in front of a general student audience at the Georgia Tech Library illustrated the advantage of increased bandwidth when using improvised ideas to generate technical solutions. By giving the entire audience note cards or sheets of paper to generate technical solutions from the initial random ideas, many more technical solutions were generated than the case were only on facilitator produced these technical solutions. A subsequent test of this higher-bandwidth approach at a meeting of the Atlanta Chapter of the Society of Women Engineers (SWE) showed it was most effective at producing technical solutions. Therefore, this approach has now been adopted as part of our best practices for these exercises.

Conclusions

From these two preliminary exercises we have learned some simple best practice principles for the use of humorous improvisation to generate engineering design ideas. In addition to the

results above, some of these conclusions were derived from specific comments on the surveys. These suggested best practices currently include:

1. Humorous improvisation should be combined with engineering idea generation in a sequential manner such that improvisation generates random ideas that seed a potential engineering design as in a MC scheme. Initial mixing of the two phenomena may reduce the effectiveness of both.

2. Improvisational exercises should be chosen to limit the potential embarrassment of the participating participants. For example they should be carried out in a classroom or conference room, instead of a public space, and initial group exercises should also be chosen diffuse any potential embarrassment (the Slide Show exercise is more palatable to inexperienced improvisers than the Props exercise).

3. In general, participants found this to be a positive experience and humor appears to have motivated the student's participation.

4. Participants were encouraged by examples in which new technical solutions were actually generated from improvised initial ideas. Any exercise that fails to reach this point does not appear to be effective. Sweeney's approach would save these initial ideas for later filtration and appears to be missing this step that may be critical to technical innovation.

5. Participants found the warm-up exercises important.

6. Participants did not find the introduction to the theory behind these exercises useful.

7. Participants believed having a leader/moderator for these exercises is important.

8. Generation of technical solutions by the entire group is more effective than generation by one moderator.

Additional workshops to test these best practices are planned for academic, corporate and educational venues throughout 2010, including the very ASEE meeting to which this paper is submitted. After additional refinement of these best practices, a systematic protocol will then be used to test the aforementioned hypothesis that MC biasing is required to make this approach effective for technical innovation. Next, the ability of technical personnel to facilitate these exercises will be tested. Failure of technical personnel to facilitate and lead such exercises would present a significant obstacle to their wide-spread use.

References

[1] "Cracking the Creativity Frontier," speech given by Dr. Joseph Bordogna, Deputy Director and Chief Operating Officer of the National Science Foundation, to the 2nd Inventors Dinner at the Rochester Institute of Technology, Rochester, NY, April 15, 2002 (http://www.nsf.gov/news/speeches/bordogna/jb020415rochesterinst.htm).

[2] Davis, S. "Engineering Innovation Requires Consistency and Creativity," *Power Electronics Technology*, March 1, 2008.

[3] "Kaist New Admission System Values Creativity," The Korean Herald, March 6, 2009.

[4] National Science Foundation Engineering Research Center Program, Solicitation NSF 09-545 (http://www.nsf.gov/pubs/2009/nsf09545/nsf09545.pdf)

[5] The Public Understanding of Engineering NAE Press: Washington, D.C., (2008).

[6] Nigel Cross, "Descriptive Models of Creative Design: Application to an Example," *Design Studies* **18**, 427–455 (1997).

[7] Kees Dorst and Nigel Cross, "Creativity in the Design Process: Co-evolution of Problem-Solution," *Design Studies* **22**, 425-437 (2001).

[8] Wang, D.; Ilhan, A.O. "Holding Creativity Together: A Sociological Theory of the Design Professions, Design Issues, 25(1), 5-21, (2009).

[9] Korn, J. "Domain-independent design theory," J. Eng. Design, 7(3), 0954428 (1996).

[10] Bryan Lawson, *What Designers Know*, Oxford/Elsevier: London, 17–19, (2004).

[11] Cavanagh, S. "Science Panel Seeks Ways to Fan Student Innovation," *Education Week*, **29**(2), (2009).

[12] Waldrop, M.M. Complexity: The Emerging Science at the Edge of Order and Chaos, Simon & Shuster: New York, 1992.

[13] De Bono, Edward Serious Creativity: Using the Power of Lateral Thinking to Create New Ideas, Harper Business: New York (1993).

[14] Koestler, Arthur The Act of Creation, Arkana: London (1990).

[15] Truex, D.; Bakerville, R.; Travis, J. "Amethodical Systems Development: The Deferred meaning of Systems Development Methods," Accting Mgmt. Info. Tech., 10, 53-79 (2000).

[16] Personal Communication, Dr. William Leahy, College of Computing, Georgia Institute of Technology (2010).

[17] Altshuller, Genrich Creativity as an Exact Science, Gordon & Breach: New York, NY (1984).

[18] Altshuller, Genrich, And Suddenly the Inventor Appeared, translated by Lev Shulyak, Technical Innovation Center: Worcester, MA (1994)

[19] Gessell, I. Playing Along: 37 Group Learning Activities Borrowed from Improvisational Theatre, Whole Person Associates: Duluth, MN (1997).

[20] Sweeney, J; Innovation at the Speed of Laughter: 8 Secrets to World Class Idea Generation, Aerialist Press: Minneapolis, MN (2004).

[21] Thilmany, J. "Improv Engineering: A Comedy Producer Imparts Idea-Generating Tips He's Learned on the Job," Mechanical Engineering Magazine, March (2005).

[22] Arabe, K.C. "No Gag, Improv Comedy Can Inspire Innovation," Industrial Market Trends, ThomasNet: www.news.thomasnet.com, March 30, (2005)

[23] Personal Communication from Julia Schmidt to P. Ludovice (2007).

[24] Molecular Operating Environment, published by Chemical Computing Group, Montreal, Canada (www.chemcomp.com)

[25] CERIUS2 published by Accelrys Inc., San Diego, CA (www.acceryls.com)

[26] Metropolis, N.; Rosenbluth, A. W.; Rosenbluth, M. N.; Teller, A. H.; Teller, E. *J. Chem. Phys.*, **21**, 1087 (1953).

[27] Gwinn, P.; Group Improvisation – The Manual of Group Improv Games, Meriwether Publishing: Colorado Springs, CO (2003).

[28] Caudron, S. *Personnel J.,* **7**(6), 63-66 (1992).

[29] Moreall, J. Humor Works, HRD Press: Amherst, MA (1997)

[30] Personal Communication, from David Schiraldi to P. Ludovice (2009).

[31] Kazerounian, K.; Foley, S.; "Barriers to Creativity in Engineering Education: A Study of Instructors and Students Perceptions," *J. Mechanical Design*, **129**, 761-768 (2007).

[32] Charyton, C.; Snelbecker, G.E.; "General, Artistic and Scientific Creativity Attributes in Engineering and Music Students," *Creativity Res. J.* **19**(2-3), 213-225 (2007).

[33] Ludovice, P.J.; Realff, M.J.; Morley, T.; Guzdial, M. "Using Collaborative Websites to Overcome Barriers to Collaboration in Science and Engineering," *Proc. from International Conference on e-Technologies in Engineering Education,* Davos Switzerland, August (2002).

[34] Wilson, J. "Skunk Works Magic," Popular Mechanics, **176**(9) (1999).

[35] Hatch, M.J.; Ehrlich, S.B. "Spontaneous Humor as an Indicator of Paradox and Ambiguity in Organizations," *Organization Studies*, **14**(4), 505-526 (1993).

[36] Lawson, B. "Cognitive Stagies in Architectural Design," from Developments in Design Methodology (N. Cross, Eds.) J. Wiley: Chichester (1984).

[37] Cross, N.; Engineering Design Methods: Strategies for Product Design 3rd Edit., J. Wiley: New York, chap. 4 (2000).