EFFICIENT ENGINEERING DESIGN USING HUMOROUS IMPROVISATION

P. Ludovice, L. Lefton

Georgia Institute of Technology, Atlanta (UNITED STATES)

Abstract

The value of improvisational activities in design is well documented. However, the connection between technical design and improvisation is imprecise and often based on indirect effects like improved listening and focus. Here we employ a useful analogy between stochastic simulation and improvisational innovation to provide a general description of how improvisation can be applied to produce innovative designs. Both stochastic simulation, and improvisational design typically have, four components: (i) formulation of a starting point or premise of the simulation or improvisation, (ii) a method for sampling the configuration of the system, (iii) a method for biasing the sampling of this system configuration to produce a desired result, and (iv) some evaluation of the results of the biased sampling to provide insight. Several types of improvisation exercises were compared to illustrate the interplay between these four steps. This comparison illustrated some basic patterns between specificity and diversity of these four components. As the specificity of the initial starting point increases, the constraints on the improvisation-based sampling method can decrease. In general, increasing specificity or constraints on any of these steps can increase idea-sampling efficiency, but will simultaneously decrease the diversity of the ideas sampled. By varying the details of these four steps, new approaches to improvisation-based design can be formulated. This scheme leads the way for a systematic development of such applied improvisation for design, which can be subsequently optimized for specific technical design challenges.

Keywords: engineering, design, design thinking, humour, improvisation, ideation, idea space.

1 INTRODUCTION

Engineering design is easily separated into two categories: (i) design that requires little or no innovation, and (ii) design of artefacts or systems that do not currently exist and require significant innovation. It is the latter category that this work addresses. The first category of engineering design includes specific design constraints that require the application of fundamental principles or known design heuristics. This type of design does not require significant creativity, just the ability to apply, and even combine disparate design principles. This former design category is addressed effectively by the majority of engineering programs, but we recognize the importance of teaching creativity required for this latter approach to engineering design. For example, the Korean Advanced Institute of Science and Technology (KAIST) now uses creativity as an admissions criterion.[1] Teaching technical students how to harness creativity through improvisational design is the general goal of our work, and this paper addresses a method for designing new approaches to improvisation-based design.

This work is based on a direct analogy between the Monte Carlo Metropolis method for stochastic simulation and humorous improvisation in the stochastic exploration of technical design space. We present this simulation/improvisation analogy as a general framework for the development of new idea sampling techniques. To illustrate the utility of this analogy, we analyse it in the context of several approaches to design and explain how it may be used to develop new approaches.

Humorous improvisation, and similar role-playing activities, have been applied to improve design.[2-12] The interactive role playing nature of this activity allows for the exploration of idea space,[3,7,13] and its humorous nature focuses on the incongruities which are compatible with innovative design.[10] Performance and role-playing exercises like improvisation can also improve secondary skills that improve the design process. These include: improving group communication,[3,14,15] reducing self-consciousness,[2,14,16] improving group focus,[3,13,14] and exploring design needs.[8,13,14] They also enhance skills like attentive listening, withholding judgement, and building on the ideas of others.[3] Such attributes are inherent in the rules of improvisation, and they mediate the tendency of engineers to exclude many ideas by rushing too quickly to judgement of feasibility and practicality.

This simulation/improvisation analogy is useful, because improvisation is actually a type of simulation. Simply put, theatrical improvisation is a simulation of life experiences used to accelerate learning experiences. Much like sport is a simulated conflict that can accelerate the learning of teamwork and strategy, improvisation is a role-playing simulation that can accelerate the learning of trust, empathy, focus and active listening skills. Normally, developing such skills requires significant effort and time because the critical interactions in which we share ideas in a vulnerable state occur with relatively low frequency in normal life. Improvisation simulates many of these interactions with a higher frequency in a constrained environment where the consequences of failure are not significant.

Ironically, innovation and humour are closely related. Both humour and innovation require a situation in which something is partially consistent and partially inconsistent at the same time. This simultaneous consistency and inconsistency is aptly described by variable conflicts in the TRIZ method for engineering design.[10,17] The same phenomenon is described by an evolutionary theory of humour that contends that humour evolved as a psychological reward for resolving conflicts that appear to be simultaneously true and untrue.[18] This evolutionary theory is essentially the same as the primary semantic theory of humour, that contends humour results from an incongruity combined with a partial similarity.[19,20] While there are many theories of humour, we contend most of them are just special cases of these theories.

Both stochastic simulation, and improvisational design typically have, four components: (i) formulation of a starting point or premise of the simulation or improvisation, (ii) a method for sampling the configuration of the system, (iii) a method for biasing the sampling of this system configuration to produce a desired result, and (iv) some evaluation of the results of the biased sampling to provide insight. These steps are varied to produce efficient simulations depending on the system of interest. There are equivalent steps in applied improvisation that allow its application, depending on the design area of interest. This work attempts to describe how these steps can be varied to design new improvisation/innovation approaches.

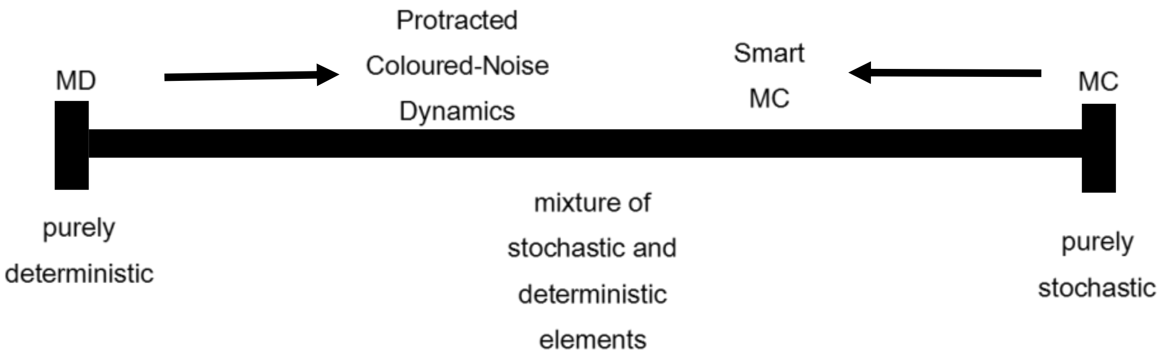

Figure 1. Spectrum of simulation models from deterministic to stochastic

Computer simulation, approaches vary from deterministic to stochastic as seen in Figure 1. Here we use molecular simulation as our example to illustrate this. Molecular Dynamics (MD) is a completely deterministic method involving the integration of differential equations that describe the energetics of the system. These are typically based on a classical equation such as Newton's second Law of motion, in which the interatomic forces determine the motion of the atoms. At the other extreme is the Monte Carlo (MC) approach, which uses statistical probabilities to evolve the system rather than differential equations. Molecules are typically moved with random translations and rotations and the individual snapshots of the system are accepted into the system ensemble based on known energy distributions derived from statistical mechanics. There are specific theoretical distributions for constant volume and temperature systems (Canonical Ensemble), and for two phases in equilibrium with each other (Grand Canonical Ensemble). In theory, both the time average of MD and the ensemble average of MC produce the same properties of the system (ergodic hypothesis). Deterministic and stochastic elements may be combined to produce models anywhere on the spectrum in Figure 1. The choice of where on the spectrum is made to increase the efficiency of the simulation. Adding stochastic fluctuations to MD can make the system equilibrate faster, or choosing more efficient moves can make MC faster.

Either the deterministic or the stochastic approach, seen in Figure 1, is efficient for the simulation of a low-density gas. Given its low density, random translations and rotations rarely produce high-energy molecular overlaps that are excluded from the ensemble. Similarly, integration of the governing differential equations equilibrate rapidly because the molecules move efficiently through its significant empty space. Given this rapid equilibration, the initial positions of the gas atoms are not critical so they may start in completely random positions. When simulating the adsorption of a gas into a porous solid, a different approach is taken as seen in Table I. Since the gas can only fit into the pores of the solid, any random placement of a gas molecule in the continuous solid would have such a high energy it would always be rejected from the ensemble average. Therefore, an MC simulation of this system would only place gas molecules in the pores at the beginning of the simulation and during any random placements during the simulation. This smarter choice of moves is referred to as Smart MC (or other names such as Force Bias MC) as seen in Figure 1. MC models are commonly used to simulate such gas adsorption systems because the diffusion of gas molecules through the pores is very slow in deterministic models.

Table 1. Various Approaches to Stochastic Simulation.

Method	***Starting Point (i)***	***Sampling Approach (ii)***	***Bias Approach (iii)***	***Evaluation (iv)***
MC gas simulation	random atom placement	random atomic movements	Canonical ensemble distribution	average properties from distribution
MC gas adsorption simulation	random placement in pores only	random placement in pores only	Grand Canonical ensemble distribution	average properties from distribution
MC polymer simulations	pre-entangled polymers	reputation and local chain moves	Canonical ensemble distribution	average properties from distribution

Deterministic models (left side of Figure 1) for searches of idea space do not exist. However, adding some stochastic fluctuations to MD simulations can improve efficiency. Globular proteins exist in aqueous solutions, and this requires the MD simulation of the surrounding water. To improve efficiency, much of the surrounding water is replaced by stochastic fluctuations that simulate the motion of the water. Polymer melts and concentrated polymer solutions move very slowly due to their high viscosity generated by the entanglements of the long polymer chains. MC models of polymers cannot rely on molecular translations and rotations because of the high energy change resulting from the slightest move of these highly entangled chains. Therefore, MC polymer simulations must rely on smarter moves where only small segments of the polymer chain are moved. MC moves that artificially snake the polymer chain along its contour (called reputation due to their similarity to snake movements), or change its local conformation can be more efficient than MD (right side of Figure 1). However, as the chains become shorter, it is more efficient to add artificial stochastic fluctuations to an MD simulation that carry out MC moves (left side of Figure 1).[21] Recently we have found that adding targeted stochastic fluctuations that increase these reputation moves can rapidly equilibrate polymer melts. This method called Protracted Coloured-Noise Dynamics (PCND) can equilibrate polymer phases four orders of magnitude faster than MD methods (see Table 1).[22] Because of the slow rate at which MC polymer simulations equilibrate, the initial conformations must pre-entangle the polymer chains to improve efficiency (see Table 1)

While we use molecular simulation as an example, there are many equivalent simulations in fluid mechanics, economics and social interactions. Even popular simulation-based video games such as SIMCITY may be modelled in both a deterministic or stochastic fashion. SIMCITY, and related video games use a stochastic MC model because of its improved efficiency. However, the aforementioned discussion employing Figure 1, and Table 1 illustrated that the stochastic elements of simulations models may vary widely. Below we examine such variations in improvisational innovation exercises using our simulation/improvisation analogy.

2 METHODOLOGY

One should note that evaluating the creativity in engineering design is inherently problematic. To determine design creativity accurately requires that its effectiveness be evaluated over years of use. Numerous technical and engineering innovations were initially ridiculed including vaccinations, the electric light bulb, and the umbrella. This initial criticism is often rooted in contextual bias. For example, the umbrella was simply the practical waterproof version of women’s parasols, and was not considered fit for use by men. To this end, a proxy is often used that consists of a qualitative evaluation by the participants of the study or by an independent panel. Currently a more objective metric is being sought by researchers S. Miller, S. Hunter, and M. Fuge, at the Pennsylvania State University, but no results have yet been published.[23]

In this work, we qualitatively compare the structure of several improvisational innovation approaches, whose effectiveness has been evaluated using the aforementioned proxy approach. We compare their structure in terms of the four components of both stochastic simulation and improvisational innovation seen in Table 1. While not all details of these methods are provided here, most of these details are provided in the cited references.

Note that sampling methods discussed here are improvisation, but they are divided into two basic categories: (i) the constrained improvisation exercises typically associated with short form improvisation, and (ii) the more free form exercises more commonly associated with long form improvisation. The former category utilizes games or exercises (sometimes called theater games, or theater sports) with specific rules designed to provide challenging constraints. These include games like “Expert translator” - where questions are answered in gibberish and are translated for the audience and “Slide Show” - where participants strike poses to mimic vacation slides, and the narrator describes the slide. In contrast, the free form approach is an improvised role-playing and scene-building that has no constraints beyond the basic rules and techniques inherent to improvisation such as using “Yes, and” to build trust and acceptance followed by adding to the story, leveraging character development, and narrative storytelling to provide structures.

3 RESULTS

Table 2 compares several applied improvisation/innovation methods in terms of the same four steps in the version of the table for stochastic simulation methods (Table 1). The specifics of these methods are discussed below, along with how the manipulation of these four steps can be modified to create new improvisation/innovation methods. The basic sampling approach for all of these examples is role-playing and storytelling. The primary rules of improvisation help to enhance this sampling method. These rules include the idea of “Yes And” which prohibits an improviser from denying the previous jump in idea space handed off to them. The next improviser must accept this offer and add an additional perturbation or jump in idea space.[24,25] Further, improvisation rules against “Wimping” or “Blocking” prevent the reduction or attenuation of these idea space jumps. For this reason, improvisation provides such effective sampling. Note that humour results accidentally when the improvisational sampling method stumbles across the aforementioned incongruity/partial similarity occurrence that results in humour. It is this incongruity/partial similarity construct that often results in innovation because this construct produces an artefact where two things may have never been put together, but might below together.[10]

Table 2. Various Approaches to Improvisational Innovation.

Method	***Starting Point (i)***	***Sampling Approach (ii)***	***Bias Approach (iii)***	***Evaluation (iv)***
IDEA	random suggestion	short form improvisation games	overlap with specified design problem	group evaluation of potential design
Speed Dating	design storyboards	need analysis or pitch	reflection on pitch	free form improvisation (user enactments)
Failure Sampling	initial technical design	free form improvisation	iterate to expose and examine failures	compare cumulative successful designs from iterations

3.1 IDEA

Improvisational Design of Engineering Alternatives (IDEA) was specifically designed as the improvisation/innovation equivalent of the PCND method described in the introduction.[10] It begins with a random suggestion typical of a short form improvisation exercise, like a person, place or thing relevant to a particular improvisation game. Note that this starting point is completely random and has no connection to the design task of interest. That is why the first row in Table 2 labels the starting point as a random suggestion. This is one of the variables that may be modified in other incarnations of the improvisation/innovation approach. This would make the random starting point of IDEA equivalent to the random starting point of the MC simulation of a low-pressure gas.

Whatever improvisation exercise was chosen proceeds in its normal fashion broadly sampling idea space due to the rules of improvisation discussed above. As seen in Figure 2 (left), the portion of the group not involved in the improvisation exercise (including workshop facilitators) writes down all the random ideas generated from the improvisation exercise on one side of a two-column list. As soon as these ideas are written, the facilitator or participant considers the design challenge of interest to see if the original idea inspires a potential solution for the design challenge, and writes it down (step 3 of 4). It can also happen there is no inspired solution and the second column is left blank. The number of blanks in the second column is inversely proportional to the efficiency of this method. The improvisation step is the divergent step, the inspired design solution in the second column is the convergent step, and the fourth step is a group brainstorming and discussion session (emergent step). The details of the application of the IDEA approach is described in detail elsewhere.[10]

Figure 2. *Educators generating innovative ideas using the IDEA approach at an American Society of Engineering Education meeting in 2013 (left). The two-column list with random and specific design ideas is visible on the left. The improvisation inspired by a design solution in Failure Sampling in a design session at a local makerspace event near Atlanta GA U.S.A. (right). The design solution being explored is on the board on the right side of this image.*

Data from two separate engineering design sessions carried out with mechanical and chemical engineering design classes at the Georgia Institute of Technology were compared via a post workshop questionnaire. Selected data from these sessions are seen in Figure 3, and more details are available elsewhere [10]. One session carried out short form improvisation followed by design brainstorming, and another used the specific IDEA method. There was no statistical difference found between the two approaches with regard to the participants' experience with, and attitude toward improvisation and creativity. However, the participants believed the IDEA session produced design ideas better, and was considered more fun. This is an encouraging result that suggests the IDEA method is potentially beneficial over improvisation alone. The fact that it was considered more fun may be that engineers are more comfortable doing improvisation when it is directly related to engineering design goals. While not statistically significant, the fact that engineers were more uncomfortable with improvisation alone is consistent with this finding (see Figure 2). This occurred even though the IDEA method uses the same improvisation techniques.

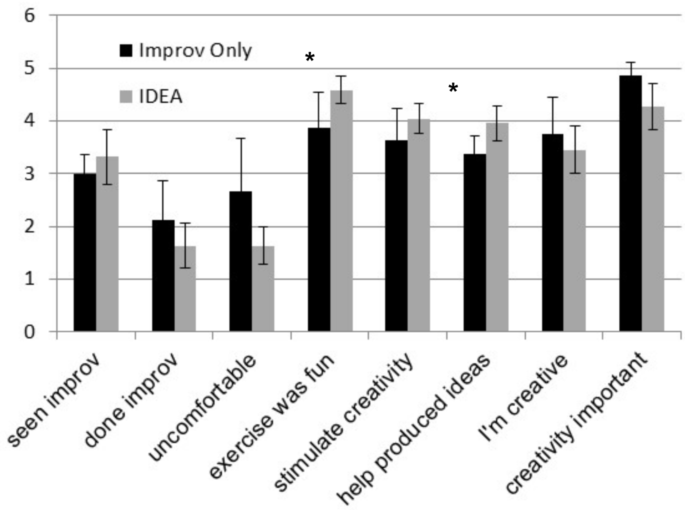

Figure 3. *Response to questions (1= complete disagree, 5=completely agree) on the post workshop survey from a 2011 chemical engineering product design course (CHBE4535) N=22, and a 2011 mechanical engineering design course (ME2110) workshop. The CHBE4535 workshop used the IDEA process, and the ME2110 workshop used only humorous improvisation without the final two steps from IDEA. The error bars are the 90% confidence intervals about the mean response and statistically significant differences are indicated above with * (p<0.05).*

3.2 Speed Dating

Speed Dating, while not developed with engineering design in mind, takes a similar four step approach as IDEA as seen in Figure 2.[13] Specifically it focuses on user-centered design in the design of computing interfaces. Speed Dating begins with a scenario based on a perceived need. These are formulated by the design team as storyboards (step 1 in Table 2). As such, this approach improves initial efficiency much like the simulation of dense polymers begins with a hypothesized entangled structure. It then consists of the following basic components:

1. **Need Validation** – This step (step 2 in Table 2) involves the presentation of paper storyboards, based on this perceived need, to a set of target users. Like improvisation, these storyboard narratives are very specific so potential users can relate to the perceived need described therein. [26,27] Interaction with the test audience helps close the gap between the design team's perceived need, and the actual need from the test audience.[13] Once this pitch is completed, the design team engages in a reflection that focuses on the actual needs and prioritizes these (step 3 in Table 2).

2. **User Enactments** – In this stage, the test users enact the scenario described in the storyboard above and explore how it works in context, much like improvisation. This helps refine the idea by exploring how a proposed design works in context. While technically not improvisation, it has all the features of the free form improvisation typical of long format improvisation so we label it as such in step 4 of Table 2.

Speed Dating has been applied with some success to analyse the needs of two-income households and how they may be assisted by smart homes.[13] This method appears to be effective in comparing many future scenarios to explore other opportunities.[28] Depending on the design challenge, any of these steps may be modified in Speed Dating to produce a variant. For example, the initial storyboards could be replaced by simpler concept cards that briefly describe a potential solution. These simple concept cards could allow the potential users to reflect asynchronously rather than all being in the same workshop session.[29]

3.3 Failure Sampling

We have recently started exploring a new approach entitled "Failure Sampling" that begins with a proposed solution. Speed Dating advanced the starting point of IDEA from a random suggestions to a specific use scenario, and Failure Sampling advances it further to analyse a potential and feasible design solution. This particular evolution illustrates the trade-off between efficiency and diversity. As the starting point of the improvisation/innovation exercise becomes more specific, the efficiency may be increased, but the diversity of potential solutions is decreased. Using the simulation/improvisation analogy, beginning with a specific solution is typical of how crystal structures are simulated. The time required for MD simulations to find a specific crystal structure is significant so simulations usually test many different approximate crystal structures and use MD to refine them. However, this specific starting point only allows the exploration of crystal structures near the initial guess (lower diversity)

Failure sampling begins with a potentially feasible solution that is drawn on a whiteboard by domain experts (see Figure 2 right side). Failure space around this potential solution is explored via a free form improvisation session driven by storytelling and characters typical of long format improvisation shows. Ideally, the characters in the improvisation are based on actual user stories. The possible failure points are used to inform subsequent design solutions in an iterative fashion. Finally, the design solutions are compared by the group to select optimal designs. We recently tested this approach at a Makerspace event near Atlanta, GA U.S.A. as see in Figure 2 (right side). This test was focused on the improvisation structure itself, and did not benefit from the more controlled problem statement and feasible initial solution which would be needed to fully explore this method. The observed diversity of ideas was broad, but we also believe that, in a proper setting, the outcomes of the method could have benefitted by more domain experts in the construction of the initial feasible solution. We plan to do further testing of this method with applied improvisers and domain experts.

3.4 Other Possible Approaches

The three aforementioned approaches provide a guideline for using our simulation/improvisation analogy for creating new approaches to the sampling of idea space for engineering innovation. While this analogy does not assist with finding the optimal approach for a particular design challenge, it does allow the formulation of numerous approaches that can be subsequently optimized. While the IDEA approach used short form improvisation games to generically explore idea space and relate it to possible design solutions, the improvisation game might be specifically chosen to address the design challenge. For example the “Commercial” Game, in which a commercial for an existing or non-existing product is improvised, could be applied to a product that addresses a specific design challenge. A similar product design game that invokes “Yes And” at every iteration of the product to add features might also be adapted for design.

Similarly, the “Armando” long format improvisation, named for its creator Armando Diaz can be adapted to design. The Armando begins with some story-telling, that is used to start a long form improvisation sketch.[30] By starting with a story about a design challenge, failure, or solution this can be used to initiate an improvisation exploration focused on a particular design challenge. Numerous improvisation games may be used to vary these innovation approaches.[31]

4 CONCLUSIONS

By invoking a mechanistic analogy between stochastic molecular simulation and improvisational innovation techniques, we have formulated a basic schema to describe applied improvisation for innovative design. This schema describes improvisational design in terms of four basic steps: (i) formulation of a starting point or premise of the improvisation, (ii) a method for sampling the configuration of the system, (iii) a method for biasing the sampling of this system configuration to produce a desired result, and (iv) some evaluation of the results of the biased sampling to provide design insight. The interplay of these steps was illustrated using three improvisational design approaches. Variation of these steps can be made to design new improvisation approaches for innovative design. Such designs are subject to trade-offs like the one between diversity and specificity in the choice of initial starting points and improvisational techniques discussed here. We are hopeful that this framework will assist in the design of new and more innovative improvisational design techniques that may be optimal for particular design challenges.

ACKNOWLEDGEMENTS

We gratefully acknowledge the assistance of the Georgia Tech Students, attendees at our ASEE workshop in 2013, and members of the Decatur Maker Space (Decatur Georgia, U.S.A.) who participated in these improvisation/innovation exercises. We also acknowledge funding for related research on applied humour from Grant # EEC-1340480 of the RIGEE Program of the U.S. National Science Foundation.

REFERENCES

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

[2] de Vries, E. "Improvisation as a tool to develop creativity mini-workshop divergent thinking." In *2014 IEEE Frontiers in Education Conference (FIE) Proceedings*, pp. 1-3. IEEE, 2014.

[3] Gerber, Elizabeth. "Using improvisation to enhance the effectiveness of brainstorming." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pp. 97-104. ACM, 2009.

[4] Kudrowitz, Barry, and David Wallace. "Improvisational Comedy and Product Design Ideation: Making Non-Obvious Connections between Seemingly Unrelated Things." In *Proceedings of the International Conference on Design and Emotion. Chicago*. 2010.

[5] Kudrowitz, Barry M. " Ph.D. Thesis, Massachusetts Institute of Technology, "Haha and aha! : creativity, idea generation, improvisational humor, and product design", 2010.

[6] Magerko, Brian, Waleed Manzoul, Mark Riedl, Allan Baumer, Daniel Fuller, Kurt Luther, and Celia Pearce. "An empirical study of cognition and theatrical improvisation." In *Proceedings of the seventh ACM conference on Creativity and cognition*, pp. 117-126. ACM, 2009.

[7] Medler, Ben, and Brian Magerko. "The implications of improvisational acting and role-playing on design methodologies." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pp. 483-492. ACM, 2010.

[8] Boess, Stella U. "First steps in role playing." In *CHI'08 extended abstracts on Human factors in computing systems*, pp. 2017-2024. ACM, 2008.

[9] Ludovice, Peter J., Lew E. Lefton, and Richard Catrambone. "Improvisation for engineering innovation." In *Proceedings of the American Society for Engineering Education National Conference*. 2010.

[10] Ludovice, Peter, Lew Lefton, and Richard Catrambone. "Humorous improvisation tailored for technical innovation." In *Proceedings of the ASEE Southeast Section Conference*. 2013.

[11] Hatcher, G., Ion, W., Maclachlan, R., Wodehouse, A., Simpson, B. and Marlow, M., 2019. Applied Humor in Creative Product Design. In *Creativity and Humor* (pp. 157-182). Academic Press.

[12] Hatcher, Gillian, William Ion, Ross Maclachlan, Marion Marlow, Barbara Simpson, and Andrew Wodehouse. "Evolving improvised ideation from humour constructs: A new method for collaborative divergence." *Creativity and Innovation Management* 27, no. 1 (2018): 91-101.

[13] Davidoff, Scott, Min Kyung Lee, Anind K. Dey, and John Zimmerman. "Rapidly exploring application design through speed dating." In *International Conference on Ubiquitous Computing*, pp. 429-446. Springer, Berlin, Heidelberg, 2007.

[14] Burns, Colin, Eric Dishman, William Verplank, and Bud Lassiter. "Actors, hairdos & videotape—informance design." In *Conference companion on Human factors in computing systems*, pp. 119-120. ACM, 1994.

[15] Svanaes, Dag, and Gry Seland. "Putting the users center stage: role playing and low-fi prototyping enable end users to design mobile systems." In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pp. 479-486. ACM, 2004.

[16] Simsarian, Kristian T. "Take it to the next stage: the roles of role playing in the design process." In *CHI'03 extended abstracts on Human factors in computing systems*, pp. 1012-1013. ACM, 2003.

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

[18] Hurley, Matthew M., Daniel Clement Dennett, Reginald B. Adams Jr, and Reginald B. Adams. Inside jokes: Using humor to reverse-engineer the mind. MIT press, 2011.

[19] Raskin, Victor. "Linguistic heuristics of humor: a script-based semantic approach." *International journal of the sociology of language* 1987, no. 65 (1987): 11-26.

[20] Raskin, Victor. *Semantic mechanisms of humor*. Vol. 24. Springer Science & Business Media, 2012.

[21] Winkler, R. G., P. J. Ludovice, D. Y. Yoon, and H. Morawitz. "Computer simulations of n-alkane melts." *The Journal of chemical physics* 95, no. 6 (1991): 4709-4714.

[22] Peters, Andrew J., Benjamin D. Nation, Daniel Nicoloso, Peter J. Ludovice, and Clifford L. Henderson. "Protracted Colored Noise Dynamics Applied to Linear Polymer Systems." *Macromolecular Theory and Simulations* 27, no. 2 (2018): 1700062.

[23] Penn State News (on-line) - https://news.psu.edu/story/484954/2017/09/27/research/nsf-grant-supports-research-define-creativity-engineering-design (viewed May 2, 2019).

[24] Halpern, Charna; Close, Del; Truth in Comedy: The Manual of Improvisation, Meriwether Publishing (1994)

[25] Gwinn, Pete; Halpern, Charna Group Improvisation: The Manual of Ensemble Improv Games, Meriwether Publishing Ltd.: Colorado Springs, CO (2007).

[26] Zimmerman, John, Nevenka Dimitrova, Lalitha Agnihotri, Angel Janevski, and Lira Nikolovska. "Interface design for MyInfo: A personal news demonstrator combining Web and TV content." In *Proceedings of INTERACT*, pp. 41-48. 2003.

[27] Kim, Jeong, and John Zimmerman. "Cherish: smart digital photo frames for sharing social narratives at home." In *CHI'06 Extended Abstracts on Human Factors in Computing Systems*, pp. 953-958. ACM, 2006.

[28] Zimmerman, John. "Designing for the self: making products that help people become the person they desire to be." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pp. 395-404. ACM, 2009.

[29] Vines, John, Mark Blythe, Stephen Lindsay, Paul Dunphy, Andrew Monk, and Patrick Olivier. "Questionable concepts: critique as resource for designing with eighty somethings." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pp. 1169-1178. ACM, 2012.

[30] Leep, Jeanne. Theatrical improvisation: Short form, long form, and sketch-based improv." Springer, 2008.

[31] Encyclopedia of Improv Games, http://improvencyclopedia.org/games.