Design Science

Review of supporting and refuting evidence for Innovation Engineering practices

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Abstract

Innovation Engineering (IE) is an educational training program that presents tools and advice on product innovation in three main categories: Create, idea generation; Communicate, communicating ideas; and Commercialize, selecting ideas to invest in further. The concepts taught in IE include common suggestions for early-stage product innovation. This paper addresses a challenge of implementing the IE program, specifically that it does not provide peer-reviewed sources or adequate data to substantiate its approach. This lack of substantiation limits effective implementation at companies. This paper also takes a step in examining IE's claims that it is 'a new science' and a 'new field of academic study', a topic motivated by the Design Science Journal's aim to serve as the archival venue of science-based design knowledge across multiple disciplines. This paper provides a compilation of academic literature that has tested the tools and advice espoused by IE. Almost all included papers contain test-versus-control experimental evidence. A mix of supporting and refuting evidence was found. Overall, the work provides a useful compilation of evidence-of-effectiveness related to common innovation and design practices that spans different design stages and is applicable for multiple disciplines and industries. This evidence comes from a variety of sources, including design, engineering education, psychology, marketing, and management. The work can also serve as an approach to evaluate overarching approaches to design in general, specifically, testing the foundations by vetting related test-versus-control experimental studies.

Key words: innovation, idea generation, ideation, product development, creativity

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1. Introduction

Innovation is widely accepted as a major force of growth in national economies (Kleinknecht 1996; Brouwer 1997; Klomp & Leeuwen 1999; Rosenberg 2004; Wong, Ho & Autio 2005; Cohen 2012), and the current president of the United States speaks that '[t]he first step in winning the future is encouraging American innovation' (WhiteHousend *n.d.*). The production of technological innovations has historically led to economic prosperity, and a new economic theory known as Innovation Economics has emerged (Atkinson & Ezell 2012). The general definition of innovation is simply the process of introducing new ideas (Merriam-Webster.com 2014*b*). In this paper, we view innovation as offering *meaningful uniqueness to facilitate economic growth* (Eureka! Ranch *n.d.*; ed. Wessner 2013), the framing provided by the U.S. National Institute of Standards and Technology (NIST) Hollings Manufacturing Extension Partnership (MEP), which considers innovation as a driver for economic growth (ed. Wessner 2013). For an innovation to spur economic growth, it must be more than just new—it must also impart financial worth. An innovation without meaningfulness to the intended audience is likely to be unsuccessful. For example, in design and engineering, new products or technologies require customers to see them as important enough to purchase and adopt.

To further articulate our definition of innovation, we compare it to the term invention. The Merriam-Webster dictionary (Merriam-Webster.com 2015*a*) has a number of definitions for invention that focus on discovery, finding, and imagination, but do *not* include the concept of economic growth or meaningfulness. Innovation and invention share the commonality of uniqueness. Invention can be important to innovation, but innovation can also exist without invention. For example, combining two different functionalities into one product can be innovative, but is not inventive. Additionally, someone can invent something that is not innovative, if that invention is not meaningful and does not provide the opportunity for economic growth. The concepts suggested by Innovation Engineering (IE) may also help with invention, but the goal of the program is to generate ideas that are unique, meaningful, and have the potential to drive economic growth.

Innovation Engineering began in 2005 (Hall & Graduates of the Innovation Engineering Leadership Institute *n.d.*), and it offers a set of tools and advice that comprise a systematic approach to innovation, akin to the training program Six Sigma for process improvement (Mehrjerdi 2011). Innovation Engineering also has similarly tiered levels of certification. From approximately 2010 to 2013, IE was a primary tool utilized by the United States Government's NIST MEP. Associated consultants in all 50 states were trained in IE to help small- and mid-sized manufacturers produce innovative products. The motivation and structure of the IE program draws inspiration from work by W. Edwards Deming, who proposed that the lack of innovation in the market was a failure of the corporate structure rather than the individual workers (Deming 1986). Innovation Engineering was developed by inventor Doug Hall, known for his work at Proctor and Gamble; founding the Eureka! Ranch (Eureka! Ranch *n.d.*); multiple appearances on reality television shows including *American Inventor* in the United States and *Venture* in Canada; and authoring a variety of books on innovation, inspiration, and marketing (Hall 1998, 2005*a*,*b*, 2007, 2009; Hall & Graduates of the Innovation Engineering Leadership Institute *n.d.*).

The IE program has had a number of training iterations with different categorizations of the same tools and advice. A fundamental categorization summarizes the tools and advice into three main categories: Create, Communicate, and Commercialize (Hall 2013). Program participants learn tools that aim to help them generate/create new ideas intended to grow organizations (typically to increase revenues), communicate those ideas to management and customers, and select which ideas to implement in commercially viable products. The goal of the organization and presentation of the program's material is to be flexible to business size and goals, and useable by students, entrepreneurs, and non-governmental organizations. Innovation Engineering includes suggestions for early-stage product innovation, such as: work in groups; use mind maps; draw

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inspiration from outside stimuli; encourage humor; keep marketing messages simple; promise something unique and quantifiable to the customer; tell a story; verify financial viability; and maintain a mission. These suggestions are presented as tools with associated worksheets and exercises. *IE Training approaches:* Some IE trainees participate in a multiday workshop called the Innovation Engineering Leadership Institute, as attended by three of the authors. Advanced 'Black Belt' training sessions are longer programs that give participants advanced training in order to teach the advice and tools of IE to others, and these sessions were attended by one author. Additionally, the University of Maine offers both a six-course minor program and a three-course graduate certificate in IE (The University of Maine 2015). There is an online version of the training available that covers similar material.

Unlike the validation of Six Sigma, where production line improvements can be readily measured, it is extremely difficult to trace market product success back to a training program, due to the number of economic and market mitigating factors. A report by the National Research Council's (NRC) Board on Science, Technology, and Economic Policy entitled '21st Century Manufacturing: The Role of the Manufacturing Extension Partnership Program' (ed. Wessner 2013)) highlights the lack of assessment of IE's effectiveness, and the need for such assessment:

> 'However, unlike lean manufacturing which dates back to the 1990s in the United States and the 1960s in Japan, there is as yet limited evidence to show that this "innovation through engineering" approach is successful' (p. 117). 'Numerous studies have addressed their [lean manufacturing methods'] effectiveness, and they are now a staple of every MBA course. This is not yet the case with the innovation program encouraged by NIST' (p. 118). 'NIST MEP has invested a very substantial amount of money (apparently at least $30 million) in developing tools [of which IE is a component]. . . There is no track record of success, and early indications from the field suggest that gaining traction with them will be a long and difficult journey' (p. 133).

These arguments indicate the necessity of a scientific validation of IE's effectiveness. Further, the IE website (Innovation Engineering *n.d.*) claims that IE 'is a new science' and 'is an accredited system and new field of academic study'. Though IE states that its teachings are based on over 20 years' research on extensive data (Eureka! Ranch *n.d.*), these 'data' are not presented in a compelling or convincing way in the related books (Hall 1998, 2005*a*,*b*, 2007, 2009), which have sparse references, or the IE seminars, which present extremely limited data in quick flashes that lack statistical verification, are not peer-reviewed, and the details of the experimental setups are not presented. Without adequate and solid proof, participants have reason to doubt the claims of testing and the small amount of data that are reported, and may feel that the testing is likely biased toward proving the success of IE methods. These doubts bring challenges in implementation at mid-level manufacturers, a goal of the NIST MEP program, as companies are understandably reluctant to take the risk of changing approaches without evidence of effectiveness.

As the aim of the Design Science Journal is to serve as the archival venue of science-based design knowledge across multiple disciplines, it serves as a

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uniquely qualified venue in which to examine IE's claims. The evidence provided by IE is inadequate to demonstrate it as 'a science', which usually contains a body of knowledge obtained through experiments and observation as well as processes of acquiring and integrating the knowledge (Merriam-Webster.com 2015*b*; Understanding Science *n.d.*). The contents of IE also lack some basic characteristics that an academic discipline requires, such as 'a body of accumulated specialist knowledge' regarding an object of research that is exclusive to this discipline, specific terminologies or technical languages, and specific research methods (Krishnan 2009). There have been no peer-reviewed publications related to the IE program. These concerns together with the NRC's report cause the tension that the IE program, which has reached out and will reach out to a large population, lacks academic support. As the first step toward this validation, it is important to ensure that its contents are based on validated knowledge. Also in line with the aims of Design Science, we review literature from a variety of disciplines, including design, engineering education, psychology, marketing, and management.

Scope of this paper: The authors investigated the effectiveness of a predefined collection of innovation-related tools and advice, namely the IE tools and advice, in an unbiased manner (note the limitations in Section 6) by performing an extensive review of related peer-reviewed literature. Each of the three IE categories was assessed separately and each tool or piece of advice in the category was addressed individually. The literature compilation focuses on test-versus-control scientific experimental studies with a statistically testable hypothesis, as opposed to observational studies.

A variety of findings are reported, including some that support, refute, and/or add on to IE recommendations. The identification of references that refute IE recommendations may also help IE to improve its training. The findings provide important academic evidence for any further judgments of IE's claims that it is 'a new science' and a 'new field of academic study'. In addition to an extensive investigation of IE, the paper provides a convenient compilation of references related to frequently espoused design and innovation practices. References for the Create category regard early-stage design, when generating creative ideas is crucial. References for the Communicate category shed some light on presenting design outcomes and how to better present designs to stakeholders. References for the Commercialize category involve making wise decisions on design selections. Addressing the different tools or advice individually allows readers to evaluate the tools and evidence for themselves, and draw their own conclusions regarding the justification of the tools to assist with innovation.

The paper proceeds as follows. Section 2 details the method and organization of the conducted literature review. Sections 3–5 step through the three IE categories; each of those three sections is broken into subsections to present each IE tool/advice within the category and the related literature. Section 6 presents the limitations of this study. Section 7 presents a discussion and conclusion.

2. Method

Each IE category (Create, Communicate, and Commercialize) offers both tools and advice: The validity and effectiveness of both types of information were investigated. The evidence presented here comes only from peer-reviewed journal

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articles and conference proceedings. The majority of the evidence presented is from scientifically designed studies that statistically tested results. Other evidence, discussed at a minimum, comes from studies that observe a subject pool and discuss overall effectiveness of a tool in anecdotal terms, as well as studies that draw recommendations from observed behavior of expert designers. The focus on test-versus-control experiments ensures that the identified evidence regarding the validity of the IE program is useful to manufacturers unfamiliar with the study of design. Outside of the theoretical engineering design community, observational studies are less well accepted.

The literature review was conducted using both print and online resources from the Iowa State University Library as well as the Google search engine. The main resource used was the Web of Knowledge, an online database of scholarly literature. Other sources include scholarly books and web articles. The online literature searches were conducted by identifying up to three keywords from each query. For example, a search for evidence showing how groups affect creative ability was conducted with the keywords: ‘Groups,’ ‘Creativity’, and ‘Experiment’. They were conducted using the Web of Knowledge, Google, and Google Scholar. Figure 1 summarizes example sets of keywords used in the online literature search. The abstracts obtained as the result of such queries were classified as relevant or irrelevant. Then, the full documents of the relevant abstracts were read and searched for evidence to either support or refute the IE tools or advice in question. References in those relevant documents were also looked through to identify other useful literature. Over 1600 abstracts were examined leading to the review of over 300 related studies. Tables 1–3 summarize the tools and advice given by the IE program and investigated by this study, offering summaries and references that support and refute IE teachings.

3. Create tools

Tools and advice in the Create category aim to assist in generating and refining innovative ideas. These innovations can be products, services, or business practices, but to be effective, the program asserts that they must be ‘meaningfully unique’. This agrees with the discussion of innovations for economic growth in Section 1: ‘meaningful’ implies a level of importance to the customer and ‘unique’ implies a novel idea. The following subsections step through the tools and advice of the Create category, offering supporting and/or refuting literature as summarized in Table 1.

3.1. Create tool: mind maps

Mind maps are graphical tools that organize and present information visually. Figure 2 shows an example, organizing the information in the Create category. Though the term ‘mind maps’ was popularized by Tony Buzan (ThinkBuzan *n.d.*), they have been used throughout history. The map has a central idea with ‘branches’ of related ideas. These grow branches of their own that continue to extend outward. Linked ideas on different branches can be connected.

This method of organization allows all ideas to be easily accessible and can help to draw connections between thoughts that may seem unrelated at first. Innovation Engineering recommends using mind maps for documenting individual and group association exercises. Kokotovich (2008) found that mind

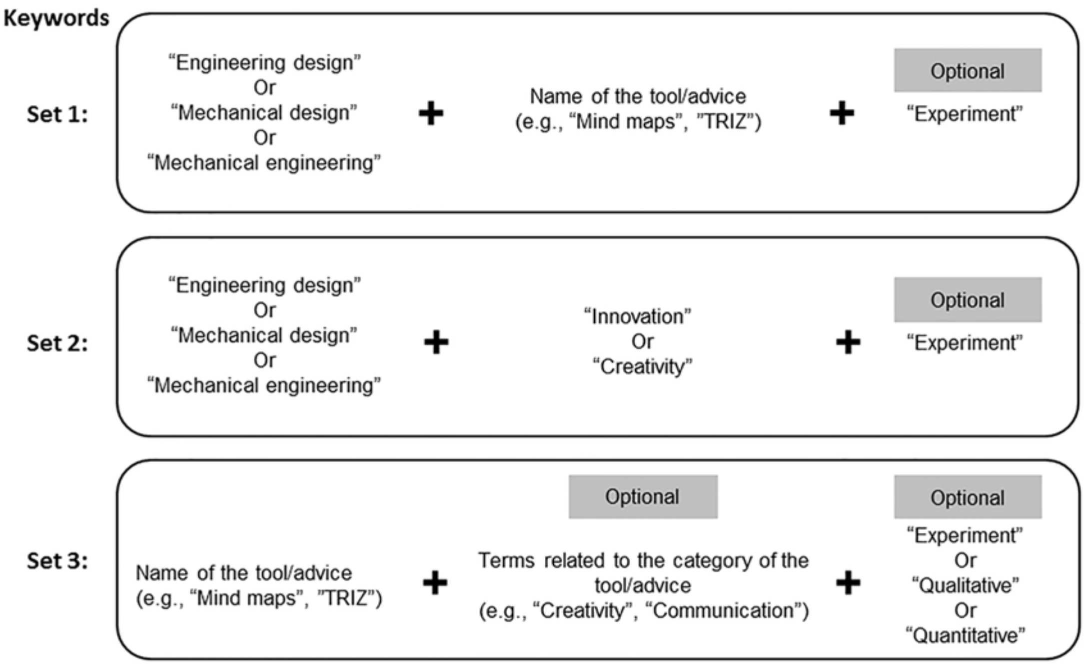

Figure 1. A summary of example sets of keywords used in the online literature search.

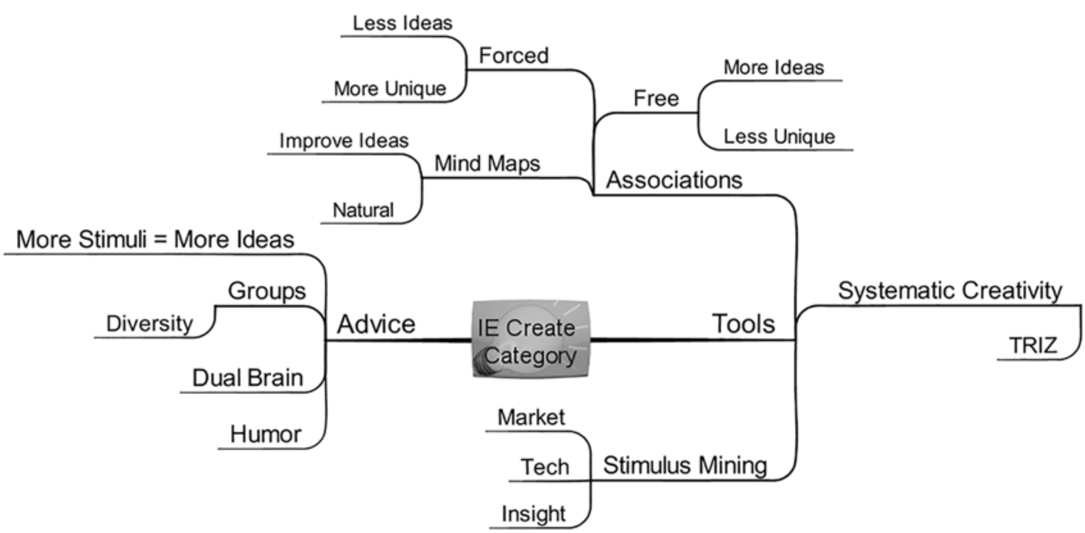

Figure 2. An example mind map generated with the concepts from the IE Create category.

maps are useful as design tools through the experimental introduction of mind mapping techniques to industrial design students. In this study, mind mapping techniques were introduced to first year industrial design students. The students used mind maps to help them generate individual project proposals, and maps

Table 1. Literature related to the IE Create category. (Letters accompanying the references in the table refer to the setting in which the experiment was conducted. 'c' represents a classroom setting; 'w' a workplace; 'l' a lab or other controlled settings; and 'o' other—such as mail surveys. References not accompanied by letters do not include scientific experimental conditions.)

Tool/Advice	Summary	Supporting literature	Refuting or mixed literature
Mind maps	Tool for graphical organization and sharing of information	(Kokotovich 2008)c, (Unalan 2007)c	
TRIZ	Tool for systematic creativity	(Hernandez, Schmidt & Okudan 2013)c, (Chulvi *et al.* 2013)l, (Birdi *et al.* 2012)w, (León-Rovira, Heredia-Escorza & Río 2008)c, (Ogot & Okudan 2006)c, (González-Cruz *et al.* 2008)c,	(Arlitt, Nix & Stone 2012)l
Stimuli	Input from an outside source	(Fink *et al.* 2010)l, (Valacich, Jung & Looney 2006)l, (Daly *et al.* 2012)c, (Howard, Culley & Dekoninck 2011), (Ocker 2005), (Roy 1993), (Cooper, Edgett & Kleinschmidt 2002), (Leonard & Rayport 1997)	(Linsey *et al.* 2010)l
Associations	The process of forming mental connections between thoughts	(Freedman 1965)c, (Coskun 2009)l, (Miller *et al.* 1970)c, (Cheng *et al.* 2010)c	
Groups	Working collaboratively with others	(Ocker 2005), (Paulus & Yang 2000)l, (McGlynn *et al.* 2004)l, (Coskun 2011)l, (Pirola-Merlo & Mann 2004)w	(Taggar 2002)c, (Diehl & Stroebe 1987)cl, (Larey & Paulus 1999)l, (Thornburg 1991)l, (Mullen, Johnson & Salas 1991)
Dual brain	Left hemisphere controls analytical thinking while right controls creativity	(Harkins & Macrosson 1990)l, (Mihov, Denzler & Förster 2010)	(Kowatari *et al.* 2009)l, (Fink *et al.* 2009)l, (Abraham *et al.* 2012)l, (Howard-Jones *et al.* 2005)l
Humor	The ability to appreciate incongruities and comical situations	(Ocker 2005), (Humke & Schaefer 1996)l, (Rouff 1975)c, (Treadwell 1970), (Ziv 1976)l	

and the creativity of these proposals was reviewed by judges, separately. The judges consistently rated work associated with higher-rated (high-quality, more complex) mind maps as more creative, and the results show a statistically significant correlation between the rating of the mind maps generated and the development of creative designs. Another study by Unalan (2007) examined the ability of graphical organizational tools to convey information. Images of different organizational tools that displayed the same information were created and shown to subjects. The subjects then judged their clarity and ability to communicate

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creative content. Mind maps were generally ranked as the best graphical tool by the subjects.

3.2. Create tool: TRIZ

The Theory of Inventive Problem Solving, commonly known as TRIZ, is a systematic creativity tool. Genrich Altshuller and colleagues examined over two million patents to extract commonalities in innovation and formulate TRIZ (Wang, Chang & Kao 2010). It provides problem-solving strategies to find creative solutions that would typically go unnoticed. The application of TRIZ relies on identifying contradictory goals or 'elements' in a design challenge, i.e. high strength and low weight. The component highlighted in IE Create is the TRIZ matrix, which maps the contradictions to a variety of engineering approaches (termed 'inventive principles' in TRIZ) to provoke creative designs. A simple, interactive TRIZ-matrix-lookup tool is available at the IE website as well as a number of unrestricted websites (TRIZ40 *n.d.*). In the IE program, when a challenge is not related to engineering, the elements are interpreted metaphorically.

Hernandez *et al.* (2013) tested the effectiveness of TRIZ on engineering students at two universities separately using a test-versus-control design on within and between subject experiments. Exposure to TRIZ increased the average novelty per subject as well as the variety of ideas. Chulvi *et al.* (2013) compared the performances of TRIZ, SCAMPER (an intuitive idea-generation method), brainstorming, and a control. Seven teams used TRIZ, seven teams used SCAMPER, one team used brainstorming, and one team used no method. By judging the solutions that the teams provided to a design problem, Chulvi *et al.* (2013) found that (1) TRIZ outperformed SCAMPER and no method in terms of the novelty of the solutions, but TRIZ was not as good as brainstorming in this dimension; and (2) both TRIZ and SCAMPER had similar performances in terms of the utility of the solutions, and this utility was better than the performances of brainstorming and using no method. However, the inclusion of only one control team calls into question the robustness of these results. A study conducted by Birdi *et al.* (2012) helped identify the benefits of TRIZ in the workplace. Power systems engineers from a multinational firm who experienced a one-day TRIZ training workshop reported significantly higher levels of creative problem-solving skills, idea generation, and creative motivation than the engineers who did not attend the training, as measured by a follow-up survey many months (the average is 33 months) after the workshop. Over a period of three years, 41% of the trainees reported submitting one or more patent applications compared to 28% of the non-trainees. As part of the follow-up survey mentioned above, subjects were asked to generate as many original solutions as possible to a design problem. On average, trainees suggested two ideas each while non-trainees submitted only one. It should be noted that many events can take place during the time gap between the workshop and the survey to influence the outcomes of the survey. While investigating learning styles, León-Rovira *et al.* (2008) found that freshmen mechanical engineering students who were given an introduction to TRIZ were scored as more creative than those who did not learn about TRIZ. Ogot & Okudan (2006) reached a similar conclusion studying first year students in an 'Introduction to Engineering Design' course placed into groups. They were given a product design task in which the experimental course sections used TRIZ techniques while the control sections did not. The experimental sections generated more unique feasible ideas both per section and per group as compared to the control sections. The effect of using TRIZ in design teams was also examined by González-Cruz *et al.* (2008). Some sections of an undergraduate engineering design class were introduced to TRIZ while others used traditional brainstorming techniques. The sections using TRIZ methods generated 115% more unique design solutions than the others.

Arlitt *et al.* (2012) demonstrated that using a matrix implementation to present the TRIZ inventive principles did not improve their usefulness. The experiment included a control condition, in which the subjects used the correct TRIZ matrix, and an experimental condition, in which the subjects used a manipulated TRIZ matrix imbedded with randomly populated inventive principles. The subjects in both of the conditions used the given matrix to solve a design problem. Arlitt *et al.* found that using the correct TRIZ matrix had no significant advantage of facilitating idea generation over using randomly provided inventive principles.

3.3. Create tool: stimuli

Stimuli provide information to living organisms and directly influence their behavior by allowing the organisms to react accordingly (Merriam-Webster.com 2014*c*). In the context of creativity, any input obtained from an outside source during the creative process can act to stimulate the mind in new ways, leading to new ideas and solutions. Finding stimuli is an important topic of IE under the general heading 'stimulus mining'. Associated methods included: (1) insight mining, where the designer receives stimuli directly from the customer in the form of observations, conversations, opinions, and surveys; (2) market mining, meaning that ideas can come from current products that are available; and (3) technology mining, in which ideas are formed by examining emerging technology.

Fink *et al.* (2010) investigated if creative cognition could be enhanced through learning the ideas of others. This study found that subjects in an alternative uses task were able to generate more unique ideas after they were presented with other subjects' ideas than subjects who did not see others' ideas. An experiment by Valacich *et al.* (2006) used a computer-simulated group to provide subjects with different qualities of stimulation during an idea-generation exercise. Fifty ideas of varying quality, as judged by experts, were entered into a database. During the experiment, a computer program supplied these ideas to subjects in a manner that mimicked the way they would have been supplied by an actual group. They found that the highest performance in idea generation was associated with the highest quality stimuli from the database.

The Design Heuristic Cards created and used in a study by Daly *et al.* (2012) provide stimuli for designers and improve ideation. The cards explain a design approach, identified from a large-scale study of academic and industry designers' practices, and show two examples of the approach in use. In the experimental study, these cards were given to freshman engineering students along with a design task. The design solutions to the design task generated by students who used the cards were more original and better developed than those generated by students who did not use the cards, as rated by two judges using a Likert-scale assessment of creativity and diversity of solutions.

Some other studies, which do not involve statistical testing, also confirm the meaningfulness of using stimuli. In an industry-based study, Howard *et al.* (2011) observed that stimuli were useful in maintaining idea-generation rates as brainstorming meetings approached their end. Feedback from the subjects confirmed that some stimuli could spark ideas and productive secondary conversations. In another study, Ocker (2005) qualitatively analyzed 10 asynchronous virtual groups' performances on initiating a computerized post office project. He found that the two groups that produced highly creative concepts both had stimulating colleagues and some initial creative example ideas. These colleagues and ideas either provided or served as stimuli that encouraged the whole group to generate creative ideas. Roy (1993), by interviewing individual designers and studying related materials, found that one designer would search for solutions from other areas or nature, which served as sources of stimuli.

Innovation Engineering emphasizes ethnographic studies as a source of customer insight, and academia widely accepts this approach as effective. Cooper *et al.* (2002) found that companies conduct ethnographic research in a 'Discovery Stage' at the beginning of the product development process. An example they provided showed that by making site visits, Fluke Corporation received first-hand information about customers' problems and needs, leading to the establishment of a very successful product line. Leonard & Rayport (1997) assert and support with examples that observing customers using products in their own environment offers five types of unique information: 'Triggers of Use', 'Interactions with the User's Environment', 'User Customization', 'Intangible Attributes of the Product', and 'Unarticulated User Needs'. This information can spark ideas for product concepts and improvements.

The concept of *fixation* presents a drawback to using stimuli to promote innovation. Design fixation occurs when a designer becomes familiar with an existing solution, and aspects of that solution then appear in their own designs. Linsey *et al.* (2010) investigated the topic of fixation with respect to engineering design. In their study, engineering design faculty members were given a design task and assigned to different task conditions. The experimental condition was given materials including an example design, which specifically violated one or more design constraints. Subjects in the experimental condition produced fewer unique solutions as compared to the control condition that received no example design. Moreover, the fixation caused by the example was so strong that these experienced designers submitted solutions that violated the same constraints.

3.4. Create tool: associations

As it relates to mental processes, association is defined as 'the process of forming mental connections or bonds between sensations, ideas, or memories' (Merriam-Webster.com 2014*a*), which is useful for generating creative ideas. Associating stimuli that are not obviously related can result in new ideas. Innovation Engineering suggests that new ideas can be combinations of old ideas. It discusses two types of associations: free and forced. Free associations are defined as those made between closely related stimuli, such as apples and grapes. When unrelated stimuli, such as a clock and an elephant, are introduced as brainstorming stimuli to find commonalities, they are referred to as forced associations. Innovation Engineering suggests that free association leads to more ideas than forced association, but the ideas generated by forced association are generally more unique.

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Association warm-up exercises were found to improve creative-thinking ability during a study by Freedman (1965). Subjects in the facilitation condition were given a stimulus word and then asked to speak associated words for 30 seconds, while those in the non-facilitation condition were asked to define stimulus words but not generate associated words. On a subsequent creative-thinking test, male subjects who completed the association exercises earned an average score of 18.05 out of 30, which was significantly higher than the average score of 14.15 of the non-facilitation condition. The difference in female subjects' scores was not as large as that for male subjects, but the trend was similar. Subjects in a study by Coskun (2009) generated more ideas during a brainstorming session after performing an exercise regarding closely linked word pairs. The subjects who worked with distantly linked word pairs generated fewer ideas. This finding suggests that free association may be more effective at generating larger volumes of ideas than forced association, but it does not speak to the quality or originality of these ideas. Miller *et al.* (1970) found that free association training improved subjects' abilities to discover additional links between stimuli on the Remote Associates Test (RAT; Mednick 1962). Subjects in the experimental condition were given 30 seconds to free-associate additional words for each of 10 stimulus words. To ensure that simply being exposed to the words was not enough to significantly affect scores, each subject in the control group read the words generated by a randomly selected subject in the experimental condition. Cheng *et al.* (2010) found association instruction directly affected creativity. After a creative-thinking pretest determined that there were no significant differences between fourth grade students, both free and forced association training was given to an experimental condition over a five-week period. This training consisted of making associations between numbers, images, stories, and music, for example, the association between the number 14 and a windsurfer. After the treatment phase, all students wrote poems to be judged on creativity. The poems by students in the experimental condition were consistently judged as more creative than those from the control.

3.5. Create tool: groups

It is commonly thought that working in groups can positively affect creative productivity, as is emphasized by IE. More people working on a common task means more opinions, experiences, thoughts, and neurons influencing the final product.

By comparing the quantities of ideas generated by groups and individuals, Paulus & Yang (2000) determined that groups could outperform individuals and nominal groups (pooled individual data) in idea generation. Using a brainwriting exercise, students sharing their ideas with others in a group led to the production of more unique ideas than students working individually or pooled individuals. Another finding from this study is that ideation performance is inhibited when the group members are asked to memorize the ideas generated by teammates. Different levels of group interaction during brainstorming activities were examined by McGlynn *et al.* (2004). University students were assigned either high-interaction groups (working face to face) or low-interaction groups (working individually but in the same area). Low-interaction groups generated more ideas than high-interaction groups, but the ideas of the high-interaction groups were of higher quality, in terms of plausibility and correctness as rated by research assistants. The high-interaction groups' consensus solutions were also rated as more plausible than the group members' individual responses. The poorer performance of low-interaction groups on generating high-quality ideas was also observed by Ocker (2005) in his qualitative research on virtual groups, mentioned in Section 3.3. He found that the group that had few to none discussions and provided little feedback on group members' inputs had very few original ideas. Coskun (2011) studied the effect of group size and session length on brainstorming activities. Groups of 4, 6, 8, 10, and 12 people were given an idea-generation task and allowed to work for either 15 or 20 minutes. The number of unique ideas generated by each group increased proportionally with the size of the group, but the size did not affect the performance of the individuals who comprised the group, suggesting no synergistic or combinatorial effects. Pirola-Merlo & Mann (2004) identified that even though a majority of the variance in group creativity was accounted for by the average group member creativity, a systematic variance still existed in group creativity after controlling for individual creativity. This means that even though the individual group members' creativity accounted for most of the group's creativity, there was evidence of improved creative thinking due to group interaction. Taggar (2002) found that working in a group can help to improve creativity if the members engage in behavior that encourages the open sharing of information. However, if group members are inadequately trained or if the group is too large, group processes can stifle creativity. This suggests that ideal creativity-fostering groups are relatively small with members who understand the importance of their behavior.

Contrary to the above findings, some previous literature (Diehl & Stroebe 1987; Mullen *et al.* 1991; Thornburg 1991; Larey & Paulus 1999) has shown evidence that brainstorming groups have poorer creativity performance than nominal groups. Diehl & Stroebe (1987) examined a number of possible ways that group brainstorming could negatively affect the productivity of the members. The data they collected suggest the existence of blocking, or the inability to share ideas because another member was sharing, as a possible hindrance to group idea generation. A blocking delay between generating and sharing an idea may prevent new ideas from fully forming.

3.6. Create tool: dual brain

Innovation Engineering discusses that creative and impulsive behavior originates in the brain's right hemisphere while logical and analytical behavior stems from the left. Although this hemispheric distinction does not actually exist, the terms 'right brain' and 'left brain' have become figures of speech pertaining to creative and analytical personality types, respectively. Innovation Engineering refers to the right brain and the left brain as descriptions of personality with remarks such as 'logical left brain' and 'radical right brain'. 'Whole brain' thinking is also discussed, with the ability to combine the strengths of both thinking types and obtain the best results.

Harkins & Macrosson (1990) tested if exercising the right hemisphere with a 10-week drawing course could enhance creativity. The experimental condition performed significantly better than the control condition in two dimensions as measured by the Torrance Test of Creative Thinking. Mihov *et al.* (2010) conducted a meta-analytic review of the literature that addressed relationships between creativity and hemispheric dominance. They provided statistical results

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showing that creativity was more likely to be associated with right-hemispheric than left-hemispheric activation.

Kowatari *et al.* (2009) conducted functional magnetic resonance imaging (fMRI) scans on both expert and novice designers during a design task to find that expert designers showed a bias toward right-hemisphere activation while the novices experienced a more bilateral response. Many experts showed a negative change in blood oxygenated level dependent signals in the left hemisphere. Both fMRI and electroencephalogram (EEG) measurement methods were used by Fink *et al.* (2009) to record brain activity during creative-thinking tasks. Subjects working on tasks such as generating alternative uses, describing object characteristics, inventing names, and completing words experienced whole brain activation rather than a bias to either side. Abraham *et al.* (2012) examined brain activity associated with conceptual expansion and found that the regions involved were those responsible for the retention, retrieval, and integration of conceptual knowledge, which are strongly lateralized to the left hemisphere. Howard-Jones *et al.* (2005) identified the brain area involved in approaching a creative story generation task as the right prefrontal cortex. In general, the literature suggests that the notion of left/right brain thinking is not accurate. While some creative processes showed hemisphere bias in brain activity, others caused whole brain activation. This activity is influenced by the experience subjects have with the creative activity being studied. Also, while certain creative processes may elicit the activation of a particular area of the brain, other areas of the brain are necessary to utilize these processes.

3.7. Create tool: humor

Humor is one of the many ways that people can interact with one another, and it is important in maintaining healthy interpersonal relationships (De Koning & Weiss 2002; Graham 1995). Humor also helps in enhancing a person's self-confidence, and self-confidence can benefit creativity (Kelley & Kelley 2013). Self-confidence is associated with self-efficacy, and the willingness to take risks in design. Highly creative design solutions often involve an element of risk. Innovation Engineering uses humor and satire to demonstrate points. Beyond applying to innovative idea generation, it was noted that humor at work will increase the productivity and mood of employees because it leads to a more enjoyable experience.

To identify the relationship between humor and creativity, Humke & Schaefer (1996) had subjects complete humor and creative-thinking measures. They found a Pearson correlation coefficient of 0.77 between scores on the Multidimensional Sense of Humor Scale and the Franck Drawing Completion Test. Rouff (1975) found a positive correlation between a subject's abilities to identify humorous incongruities and RAT scores. Treadwell (1970) found significant positive correlations between 'humor creation scores', measured by a Cartoon Test, and three creativity scores: RAT scores, Gestalt Transformations test scores, and Novelty of Productions scores. Ziv (1976) investigated the relationship between laughter and creative thinking. A humorous recording, selected due to its ability to produce high amplitude and long duration laughter in subjects listening to it, was played for subjects in an experimental condition prior to a Torrance Test of Creative Thinking. The subjects who listened to the recording performed significantly better on the test than the control condition that did not. In Ocker's (2005) observation of virtual groups' performances, he noticed that witty but task-related humor was involved in the two most creative groups' internal interactions, which suggests positive effects of humor on creativity.

4. Communicate tools

Scientists and engineers are often stereotyped as poor communicators; according to recent Graduate Record Examinations scores, engineering graduate degree applicants had some of the lowest average verbal reasoning and analytical writing scores of all intended majors (Educational Testing Service 2013). Furthermore, technical information is typically detailed and complex, so even skilled communicators may have trouble presenting it. Innovation Engineering emphasizes that it is necessary to effectively communicate innovative ideas to the intended audience. This section presents literature related to the tools and advice of the IE Communicate category, as summarized in Table 2.

4.1. Communicate tool: benefit promise

Benefit promise is the IE term for the specific benefit that an innovation will provide to the audience. The program stresses that it is important to tell people why they should care as opposed to simply listing features of a product or service. A study by Cooper & Kleinschmidt (1993) showed the relative importance of communicating product benefits to product success. After examining 109 different products from chemical companies, they identified the traits that lead to successful products. Featuring a specific benefit of importance to the customer ranked as the fourth most important trait of success, behind traits that involved the product's relative quality and price as compared to the competition.

4.2. Communicate tool: simplicity

In communication, simplicity refers to targeting the amount and type of information being exchanged. More information communicated means more to remember. Innovation Engineering recommends that all communications be as simple as possible to allow the most important aspects of the message to be received and remembered.

It is documented in Miller's review (1994) that people can only discriminate about seven levels of single-dimensional stimuli (for example, seven numbers), indicating the limited information processing capabilities of humans. While the general recommendation of simple communication is featured in general-audience scientific books (Heath & Heath 2007; Maeda 2006) there was limited academic research identified by the authors. One reason for this could be that simplicity in communication is assumed to be common sense.

Some sources were located that refute the benefit of simple communications. Shedler & Manis (1986) tested the effect additional but unrelated details have on the credibility of arguments. Subjects in two conditions heard equal numbers of opposing arguments about the fitness of a mother and were asked whether they thought the mother should retain custody of her child. One condition heard additional details for the positive arguments while the other condition heard additional details for the negative arguments. Even though the details were unrelated to overall paternal fitness, the additional information significantly affected the subjects' judgments in both conditions. Another study by Macklin

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Table 2. Literature related to the IE Communicate category

Tool/Advice	Summary	Supporting literature	Refuting or mixed literature
Benefit promise	Why people should care	(Cooper & Kleinschmidt 1993)w	
Simplicity	Keep the message simple and concise	(Miller 1994)	(Shedler & Manis 1986)l, (Macklin, Bruvold & Shea 1985)l
Tell the truth	Be honest and open with customers	(Trifts & Haubl 2003)c, (Corbitt, Thanasankit & Yi 2003)o, (Jarvenpaa, Tractinsky & Vitale 2000)c, (Lau & Lee 1999)o, (Settle & Golden 1974)c, (Anderson 1973)l	(Liberali, Urban & Hauser 2013)o
Repetition	Repeat your advertising message (Note potential for oversaturation)	(D'Souza & Rao 1995)l, (Ray & Sawyer 1971)l, (Mayer 1983)l	(Cacioppo & Petty 1979)l
Provide proof	Supply examples of your innovation working	(Liberali *et al.* 2013)o, (East, Hammond & Lomax 2008)o, Trifts & Haubl (2003)c, (Corbitt, Thanasankit & Yi 2003)o, (Jarvenpaa, Tractinsky & Vitale 2000)c, (Bearden & Shimp 1982)o, (Thorelli, Lim & Ye 1989)o, (Maddux & Rogers 1980)l	(Boulding & Kirmani 1993)l, (Fu & Chen 2011)o
Include a number	Including objective information improves communication	(Holbrook 1978)c, (Rossiter & Percy 1978)w, (Davis 1993), (Mader 2002), (Hauser & Clausing 1988)	
Tell a story	The inclusion of a plot entices people	(Green & Brock 2000)c, (Pennington & Hastie 1988)l	

et al. (1985) examined how the readability of a print advertisement affected a reader's ability to retain important information. Different versions of a printed advertisement were designed and statistically verified to contain the same information and vividness but have different levels of readability. These were shown to subjects whose recall was subsequently tested. The experiment revealed that the readability did not affect the ability to recall ad claims, attitude toward the brand or ad, or purchase intent.

4.3. Communicate tool: tell the truth

Innovation Engineering advises that honesty in communications imparts trust between a company and its customers. The Edelman Trust Barometer (Edelman 2013) collected information from 26 000 public subjects in 26 countries to identify attributes that encourage trust in companies. Honest communication from companies was identified as one of the most important attributes. Trifts & Haubl (2003), Corbitt *et al.* (2003) and Jarvenpaa *et al.* (2000) all show that the perceived trustworthiness of an Internet vendor is positively correlated with the probability that customers choose to purchase from those vendors. A mail survey conducted by Lau & Lee (1999) identified that brand performance is a strong predictor of trust in a brand, and that trust in a brand contributes to brand loyalty. Subjects in a study by Settle & Golden (1974) were shown advertisements where a new product was compared to the current best-selling alternative. One study condition was shown a version that claimed the new product was superior in five of five areas while another condition was shown a version that only claimed superiority in three of five areas. The subjects shown the latter reported a higher believability for the advertisement. Anderson (1973) investigated the relationship between expectations and product performance; when subjects were given realistic expectations of a pen's performance, they rated its performance higher than when given overly positive expectations.

One study offers insight into how much honest information should be supplied. Liberali *et al.* (2013) found that proactively supplying information that made brands vulnerable to criticism did not increase subject trust in the brand. Honesty should be paired with simplicity of communications in a strategic manner.

4.4. Communicate tool: repetition

Innovation Engineering advises that repeating a product message increases memorability. D'Souza & Rao (1995) tested the effect of repeating a specific advertisement relative to that of competitors. They found that higher repetition rates resulted in significant increases in top-of-mind awareness, brand preference, and brand choice. Ray & Sawyer (1971) exposed female shoppers to slides of advertisements with varying repetition rates, and then the shoppers took a product survey. Repetition rate had the most significant effect on advertisement recall, with an almost 40% increase when comparing a single exposure to four exposures. Purchase intention for the products shown also increased significantly. The significant effect of repetition on information recall is also supported by the literature in psychology (Cacioppo & Petty 1979; Mayer 1983). Mayer (1983) found that repetition not only increased the amount of recalled information that was related to the provided recordings, but also had effects on what was remembered. The recall of conceptual principles benefited from repetition more than the recall of details such as concrete analogies and facts.

Cacioppo & Petty (1979) found that message repetition increased the amount of information that was recalled and that as the number of repetitions increased, subject agreement with the repeated statement first increased and then decreased. This suggests that there may be an oversaturation point in message repetition that could have a negative effect on innovation communication.

4.5. Communicate tool: provide proof

Providing proof presents potential customers with concrete evidence to support a marketing claim. Innovation Engineering examples of proof include test results, company pedigree, testimonials, and guarantees. Innovation Engineering advises that more proof is better as long as the proof is meaningful.

Liberali *et al.* (2013) tested if access to direct product experience, print and online resources, word of mouth, or recommendations from trusted advisors would alter customer brand preferences. The study found that providing direct product experience and testimonials significantly improved brand consideration and trust in a brand. East *et al.* (2008) used mail-in surveys to measure the change in purchase intent after exposure to positive and negative word of mouth. The results showed that positive word of mouth improved the subjects' probability of purchase by an average of around 50% while the negative word of mouth decreased the average purchase probability by 25%. Multiple references from Section 4.3 (Corbitt *et al.* 2003; Jarvenpaa *et al.* 2000; Trifts & Haubl 2003) explain that customer trust improves brand consideration; this trust can be affected by the proof that is available.

Bearden & Shimp (1982) considered product warranty as an extrinsic cue that would influence customers' perceptions of innovative products. By constructing models of customers' risk perceptions and overall affect toward two new product concepts, they proved that a warranty mediated customers' affective responses to innovative products via perceptions of risk. Thorelli *et al.* (1989) found a significant effect of warranties on three measures of product evaluations: perceived quality, overall attitude, and purchase intention of the product. Boulding & Kirmani (1993) found that a better warranty helped a high-credibility firm to achieve better customer perceptions of product performance and overall quality, as well as to improve purchase intent. But this was not the case for a low-credibility firm, which suggests an interaction with trust. Fu & Chen (2011) present mixed findings on offering guarantees. In a study examining online auctions, they identified that while offering a refund guarantee did increase the price premium of the items up for bid, it did not affect the time until the first bid, number of bidders, or number of bids. This means that the customers were willing to pay more knowing they were guaranteed a refund, but the guarantee did not attract more interest or additional customers. In the psychology literature, Maddux & Rogers (1980) found that people who provided supporting evidence while arguing a position were significantly more likely to persuade a subject, independent of the arguer's expertise and physical attractiveness.

4.6. Communicate tool: include a number

Innovation Engineering suggests that including numbers makes for concrete and understandable communications; for example, 'this toothbrush design removes three times as much plaque as the leading brand'. The number three in this marketing message gives the audience a value to place on the product.

Holbrook (1978) had subjects read and rate advertisements that were either objective (i.e., '27 miles per gallon') or subjective ('truly excellent gas mileage'). Objective advertisements were statistically associated with higher brand attitude and claim belief than subjective ads. Rossiter & Percy (1978) had customers rate a product after seeing its advertisement. Subjects who saw ads that included concrete information, such as 'Bavaria's number one selling beer for the last ten years', responded more favorably to the product and the brand than those who saw less concrete statements like 'Bavaria's finest beer'. Davis (1993), in his literature

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review, strongly suggested the use of numerical data and specific statements in environmental claims.

It is also important to include numbers and be specific when communicating internal product development goals. Six Sigma is a strategy used in industry to 'improve profitability, to drive out waste in business processes and to improve the efficiency of all operations that meet or exceed customers' needs and expectations' (Antony & Banuelas Coronado 2002, p. 24). Design for Six Sigma requires the identification of numerical customer requirements and engineering specifications (Mader 2002). These specific goals can improve the performance of the project as proposed by Linderman *et al.* (2003) and can also facilitate communication within a design team. Similarly, House of Quality, which is a 'basic design tool of the management approach' (Hauser & Clausing 1988, p. 63) contains steps for identifying specific customer requirements and engineering specifications. These steps help benchmark development activities and set target design values (Hauser & Clausing 1988), and are particularly useful for interdisciplinary product design teams.

4.7. Communicate tool: tell a story

A good story captivates audiences both intellectually and emotionally, and IE advises their use in communicating marketing messages. Green & Brock (2000) gave subjects a short story to read and told them that it was either fictitious or real. A post-survey identified that subjects who reported higher transportation by the story (deeper mental processing/emotional involvement) rated the story's situation more realistic and the characters more favorably, whether or not they were told the story was real. The positive effect of arranging facts into a story was examined by Pennington & Hastie (1988). Subjects acted as jury members for a mock trial, and after being presented evidence, were asked to determine if the defendant was innocent or guilty. The study found that when evidence supporting one verdict was presented in a story-like order, the subjects were significantly more likely to pass that verdict and reported significantly higher confidence in their decisions. This shows that stories not only influence judgments and perceptions, but also improve the persuasiveness of an argument.

5. Commercialize tools

Revenues and profits can measure product innovation success. But variables that influence these metrics, such as government policy, organizational change, and distribution, lie beyond a designer's control. The customer base also determines profitability, and shifts in public opinion can have a major impact. Despite external challenges such as these, a development team must decide which innovative ideas to pursue, and which to table. Innovation Engineering offers sound advice for mitigating the risks that accompany the innovation processes, but the associated commercialization tools lack sophistication and accuracy. State-of-the-art approaches are presented below and summarized in Table 3.

5.1. Commercialize tool: do one thing great

Innovation Engineering advises companies to identify a core benefit that they can offer customers, and use this benefit to drive the mission and focus of the company.

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Table 3. Literature related to the IE Commercialize category

Tool/advice	Summary	Supporting literature	Refuting or mixed literature
Do one thing great	Reduce the number of options offered	(Boatwright & Nunes 2001)w, (Iyengar & Lepper 2000)cwo, (Redelmeier & Shafir 1995)o, (Magretta 1998)	(Oppewal & Koelemeijer 2005)o
Predicting sales and selecting ideas	Fourt–Woodlock recommended	(Fourt & Woodlock 1960)o	(Yates 2003), (Michalek, Feinberg & Papalambros 2005; Train 1986), (Frey *et al.* 2009), (Papalambros & Wilde 2000), (Hazelrigg 1998), (Wassenaar & Chen 2003), (Day 2007)

This can mean, for example, eliminating product offerings that are auxiliary to this core benefit, or changing the manner in which product benefits are presented. Supporting this, Boatwright & Nunes (2001) found that removing low-sales items from grocery store shelves increased average category sales. Although the reduction in options caused some customers to leave the retailer, the majority of customers whose preferred brand was cut adopted a different brand. Iyengar & Lepper (2000) examined the effect of limiting the number of choices available. Subjects in a grocery market were offered free samples from a large selection of jams (24 options) or a reduced selection of 6 options. The large selection set attracted more subjects to investigate the offer, but produced fewer final sales than the limited set. Redelmeier & Shafir (1995) investigated how decisions were altered by the addition of new options. When presented a hypothetical situation in which subjects had plans to complete one activity but were then offered a single more attractive alternative, only 21% chose the original activity. Interestingly, when subjects were offered two better alternatives, 40% chose to follow through with the original activity. When given multiple alternatives, a sizeable number of subjects avoided making a switching decision.

In a report of an interview with Dell's founder, Magretta (1998) emphasized the importance of focus and specialization in Dell's success. Dell did not decide to make every piece that was needed for a computer, instead purchasing well-made components from other companies. They focused on 'delivering solutions and systems to customers' (Magretta 1998, p. 74), creating unique value for its customers and developing the company.

One study located does potentially refute the idea of limiting offerings. Oppewal & Koelemeijer (2005) mailed surveys to customers that asked for opinions about a variety of flower assortments. When subjects were given more assortment options, the average evaluation across assortments significantly improved, in a linear manner. However, this study did not investigate how many subjects purchased one of the assortments.

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5.2. Commercialize tool: predicting sales and selecting ideas

After refining innovative ideas, it is necessary to select ideas to focus on developing them, while putting other less-promising ideas aside. This selection process can be partially guided by advice, such as Do One Thing Great: if the idea strays too far from the core company mission, it may not be right for development. But, ultimately, the success of an idea must be linked to metrics such as predicted revenues. As Herstatt, Verworn & Nagahira (2004) observed, companies use economic criteria to assess their innovative ideas. The selection can be done by experts with simple selection criteria (Ferioli *et al.* 2010), both objective and subjective, but involving explicit tools can better support the selection. Innovation Engineering recommends the Fourt–Woodlock equation (Fourt & Woodlock 1960) as a tool to aid in this evaluation. The equation, as it is presented by the IE program, is

$$AS = FDM \times TR \times FPR + FDM \times TR \times RR \times RPR \times NRP,$$

where AS is the annual sales forecast, FDM is the number of final decision makers (potential purchasers), TR is the trial rate, FPR is the first purchase revenue, RR is the repeat rate, RPR is the repeat purchase revenue, and NRP is the number of repeat purchases. It should be noted that these variables are not the same in all representations of the equation, but the meaning of the variables used does not change markedly from one version to another.

To create this equation, Fourt and Woodlock used trial rate and repeat ratios based on observed test markets and real purchase data, and made a number of assumptions about the consistency of the environment in which the products would be sold. The assumptions were that the distribution, promotional expenditures, prices, competitive activity, product, and packaging would not change substantially during the time of the estimate. In situations where these assumptions held and the rates could be determined by an initial test sample, this method predicted volume changes within 5% of the actual values. If the prediction shows that a product will bring substantial profit, a company can justify mass production. Conversely, if the forecast implies a poor return, the company can edit the offering in an attempt to improve the prediction, or scrap the offering altogether. As presented by IE, the equation did not include rates determined by an initial test market or stress on any of the stated assumptions. However, in situations observed by Fourt and Woodlock where one or more of the assumptions were violated, the estimate became much less accurate. Innovation Engineering also suggested estimating the trial and repeat rates, which will likely lead to further loss of accuracy.

Test markets have been used for many years, and forecasting models have been generated to predict new product performance; see Parfitt & Collins (1968), Eskin (1973), Nakanishi (1973), Jain, Mahajan & Muller (1995) and Decker & Gnibba-Yukawa (2010). These models, however, are more complex than the Fourt–Woodlock equation, and thus more difficult for a general audience to adopt. The Bass diffusion model (Bass 1969) for adoption rate prediction has been studied substantially and modified to accurately predict specific adoption rates for specific markets (Bass, Krishnan & Jain 1994; Satoh 2001; Li & Yang 2006; Diao, Zhang & Jia 2009; Tseng & Hu 2009). However, this model assumes that

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the innovation will end with complete adoption across a population, like personal computers or television.

The authors offer alternative approaches for selecting innovative ideas. Multi-Attribute Utility Theory (MAUT), based on Utility Theory in economics, enables idea selection by comparing overall utility of each idea in decision makers' perspectives (Yates 2003). The ideas are first evaluated in terms of multiple criteria respectively with corresponding utility functions; then the overall utility of an idea is usually obtained in an addictive manner for further comparisons. Applications of the MAUT include comparing an innovative parabolic solar cooker against existing cooking devices in India (Pohekar & Ramachandran 2006) and optimally positioning a product innovation in an existing market (Gavish, Horsky & Srikanth 1983). Choice share (amongst potential customers) of innovations can also be estimated using customer-survey-based methods such as discrete choice analysis (Train 1986, 2009; Wassenaar & Chen 2003; Michalek *et al.* 2005; Kumar *et al.* 2009; Zhang, Gensler & Garcia 2011).

Simple and effective, Pugh matrixes are widely used by engineers for idea selection (Honkala, Hämäläinen & Salonen 2007; Ullman 2009). Design alternatives are evaluated in terms of a set of criteria against a base design concept. A scoring system (1, 0, −1) indicates that a design alternative performs better, equal to, or worse than the base concept for each criterion. A total score for each alternative is tallied, the best aspects of different ideas are combined, and the process continues iteratively until one idea is clearly the best alternative. Frey *et al.* (2009) evaluated this method by quantitatively modeling its implementation process. They confirmed the effectiveness of this method during the early design stage, and found that it facilitated the decision convergence with objectivity.

Idea selection can also be guided by formal engineering optimization approaches combined with market share predictions. Interdisciplinary optimization mathematically finds the 'best' alternative as evaluated by an objective function subject to conditions including customer preferences and design constraints (Papalambros & Wilde 2000), and has identified optimal product designs with predicted market performance (Michalek *et al.* 2005; MacDonald *et al.* 2009; Kelly *et al.* 2011).

Decision-Based Design (DBD) (Hazelrigg 1998; Li & Azarm 2000; Gupta & Samuel 2001; Wassenaar & Chen 2003; Wassenaar *et al.* 2005) helps select a product design alternative through systematic steps. Hazelrigg (1998) offers a DBD framework that considers factors like design variables controlled by designers, product attributes valuable to customers, demand, price, and time. It allows for the incorporation of methods like discrete choice analysis and profit optimization, and can be adapted to a variety of design problems (Li & Azarm 2000; Gupta & Samuel 2001; Wassenaar & Chen 2003; Wassenaar *et al.* 2005). Wassenaar & Chen (2003) use DBD to identify the design alternative with the largest net revenue, demonstrated with the design of an electric universal motor.

Day (2007) suggested using both the risk matrix and the R–W–W ('Real, Win, Worth it') screen to determine whether an innovation should be implemented or not. Positioning an innovation on the risk matrix, which was defined by two familiarity dimensions (the company's familiarity with the new product and its familiarity with the intended market), allowed an estimation of the innovation's probability of failure. The R–W–W screen provided a three-level question set that

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the company should answer for its innovations, which helped the company assess the innovations for screening.

6. Limitations

The literature review focuses on tools and advice covered in the IE program. There are other tools and advice that can help with innovation but are not mentioned in this paper, including ones that can be used in place of IE's tools and advice. When evaluating the effectiveness of each tool and advice, this paper focuses on comparing the related supporting and refuting literature. This comparison has a notable limitation: there is an intrinsic unbalance between the quantities of supporting and refuting literature. Evidence refuting or disproving effectiveness is more difficult to find because publishing a paper on an unsuccessful experiment is more difficult than publishing a paper on a successful one. A potential alternative to refuting literature is literature that demonstrates the solid performance of a competing tool.

Some tools suggested by IE have known or potential limitations. For example, the TRIZ matrix was developed based on patents from more than 50 years ago, and those patents are primarily mechanically oriented. In addition to the uselessness of the matrix implementation discussed in Section 3.2, researchers have found that the TRIZ matrix has limited ability to interpret patents from more recent years and modern industries (Mann 2002; Sheu, Chen & Yu 2012). Eliminating product offerings, as a way to 'do one thing great', will have varied effectiveness dependent on product category, the sophistication of the design solution, and cultural differences, for example, variety-seeking behavior.

Importantly, the Create category of the IE program focuses only on certain approaches. Here we discuss others that are not mentioned in the IE training, and for which we were not able to locate test-versus-control experiments that demonstrate the validity of the approach. This does not imply that they do not work, only that they are beyond the scope of this paper's discussion and the authors' abilities to demonstrate their effectiveness. For example, the Concepts–Knowledge (C–K) Theory has been used in both the academics and the industry to help with innovation (Agogué & Kazakçi 2013). The C–K Theory is a design theory that considers design as related to two spaces: the 'Concept' space and the 'Knowledge' space; this theory also explains that creativity is due to certain expansions of the two spaces (Hatchuel & Weil 2003). This rationality of creativity can guide design processes to achieve creative outcomes systematically (Hatchuel, Le Masson & Weil 2004). In addition, there are product-design-related methods that were not specifically created for facilitating creativity, but could be beneficial to it. Functional analysis decomposes a product's overall function into a set of detailed and manageable subfunctions so as to help understand design problems and generate concepts (Ullman 2009). The subfunctions, which can be defined using the functional basis (Stone & Wood 2000; Hirtz *et al.* 2002), serve as the bases for concept generation. This approach helps mitigate designers' tendencies to focus on specific solutions in the early design stage (Bryant *et al.* 2006). Functional analysis also encourages designers to seek different solutions and ideations (Berawi 2011). Coatanéa *et al.* (2014) incorporated casual graph and dimensional analysis into the early design analysis stage, which can help extract contradictions in the design problems systematically. Identifying these contradictions points the way to unique design solutions and thus innovation.

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7. Discussion and conclusion

The literature review supports the use of the majority of IE tools and advice, as summarized in Tables 1–3. Some references challenge IE suggestions, such as Arlitt *et al.* (2012) who showed that a random selection of the inventive principles could be as effective as using the TRIZ matrix to arrive at particular inventive principles. Linsey *et al.* (2010) demonstrated that the use of stimuli can decrease creative output and even cause violations to design criteria via fixation. Mullen *et al.* (1991), Thornburg (1991) and Larey & Paulus (1999) observed that creativity performances of interactive groups were not as good as those of nominal groups, which implies that group-based processes can inhibit creativity. Diehl & Stroebe (1987) and Taggar (2002) identified reasons for this possible inhibition. Hemispheric brain activation research (Howard-Jones *et al.* 2005; Fink *et al.* 2009; Kowatari *et al.* 2009; Abraham *et al.* 2012) gives evidence that the entire brain is necessary for the generation and implementation of creative ideas, as opposed to a left/right brain duality. Macklin *et al.* (1985) and Shedler & Manis (1986) showed that it can be beneficial to increase complexity by including extra and possibly even irrelevant details, thus refuting the idea that simplicity always improves communication. Fu & Chen (2011) found that offering a refund guarantee for online auctions had limited effects on bids. Oppewal & Koelemeijer (2005) proved that increasing the number of offerings can lead to more positive reactions from customers. Alternative approaches to the Fourt–Woodlock equation are suggested in Section 5.2. The refuting evidence identified here is not all-inclusive. There is the possibility of limitations or shortcomings that remain unidentified due to the bias toward publishing successful studies.

The IE Create category contains tools and advice that aim to assist in the generation and refinement of innovative ideas. These tools/advice can be associated with specific stages of the creative process. Wallas (1926) divides the creative process into four stages: Preparation, Incubation, Illumination, and Verification. In the Preparation stage, people actively seek information and investigate the problem at hand from all aspects; in the Incubation stage, there are no conscious efforts spent on the problem, but mental processes related to the problem continue unconsciously; the Illumination stage refers to the moment that a creative idea comes to mind; finally, this creative idea is refined and verified in the Verification stage (Wallas 1926). 'Mind maps', 'TRIZ', 'stimuli', 'associations', and 'groups' are all related to the Preparation stage as they assist people in actively working on the creativity task. 'Stimuli' and 'association' may be also related to the Incubation stage, because the stimuli that people viewed and the associations they made in the earlier period may play a role in the unconscious mental processes. 'Groups', however, may negatively affect the Incubation and the Illumination stages. The Incubation stage takes place when people are having a break and are not 'thinking' about the creativity task; but when people are in groups working on the task, this is very difficult to do. Outside group discussions may further distract a person's attention and cause him or her to miss any ideas that suddenly arise in the Illumination stage. 'Humor' relates to the Incubation stage as humor can create a divergence from the task and diffuse concentration. 'Dual brain' can be related to all four stages of the creative process; it is possible that different stages use different parts of the brain and initiate different activities in the brain. These tools/advice also differ in their aims and focus. All the tools/advice suggested by IE, except for TRIZ, are generic and can be applied to a wide variety of problems,

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while TRIZ mainly addresses engineering problems. Some of the tools/advice are local and focus on the problem at hand, such as mind maps; and some others have a wide spectrum, such as humor and dual brain. It is important for the readers to consider these factors when choosing the tools/advice for use.

In the studies summarized in this paper, creativity is judged in numerous ways, for example, by the volume of ideas generated, quality of ideas as rated by judges, and results of tests such as the Torrance Test of Creative Thinking. The translation of effective improvement in creativity from the lab environment to the workplace is a complex undertaking. Table 1 notes the studies that occurred in workplace scenarios with a 'w', and these are perhaps the most effective studies in supporting the recommendations of IE, which is geared toward workplace settings.

The review identifies areas that require further research. Many references included in Section 3 incorporate idea-generation tasks, but only a few involve product design tasks. Additionally, design spans a wide variety of industries. Service-oriented problem solving, management issues, and governmental policy resolution all require creativity, and could be good testing grounds for promising creativity tools. A few references also mentioned the importance of motivation in creativity, although this subject was not explicitly included in the search. When subjects in the studies were asked to be creative or knew that their creativity would be judged, it prompted them to respond more creatively. This was explicitly documented by Miller *et al.* (1970) and Howard-Jones *et al.* (2005). The IE program is likely most successful when companies want to improve their innovation skills. The relationship between motivation and innovation could be studied in more depth, especially in workplace settings. There were almost no studies identified that tested interaction effects between the different approaches discussed here, with the exception of the relationship identified between trust and communication of marketing message. For example, a study that investigates both the use of humor and forced associations on creativity would yield interesting results.

The literature review shows that some commonly used innovation-related tools and advice that are 'assumed' to work by many methods and professionals would benefit from academic support in addition to anecdotal evidence. Such tools and advice include 'mind maps', 'benefit promise', 'simplicity', and 'tell a story'. These tools/approaches seem reasonable and their usefulness obvious, but they would benefit from research on their limitations and best-practice implementations. The literature review also shows that some advice, like 'work in groups' and 'dual brain', has comparable amounts of supporting and refuting evidence. Though the concepts are simple, implementation is complex and worthy of in-depth research in order to establish clearer guidelines.

This paper serves as an approach that can be used to evaluate other similar training programs when experimental tests are impossible at the moment due to limitations of budget, time, or practicality. Evaluating the IE program by assessing its components individually examines the foundation of the program. It enables potential participants to the program to justify the use of the different tools for themselves. The evidence (both positive and negative) found for each individual tool helps the participants to select subsets of tools for more in-depth uses with more confidence. The identified refuting literature also lays out caveats and limitations for using those tools. However, this evaluation approach does not consider the training procedures, activities, or exercises in the IE program.

These factors could have some effects on the participants' learning outcomes. The evaluation approach here also does not consider the synthetic effects of the tools. Extrapolating this idea, the best test of IE's effectiveness would be a longitudinal study that incorporates all tools and advice in a test-versus-control environment, with experts and novices, in industrial and academic settings, and then relates experimental outputs to financial gains. It is possible that metrics such as trial markets or Kickstarter (Kickstarter *n.d.*) donations could be used to test potential for financial gain. If such a study could be conducted and positive results found, it would be a great benefit to IE's credibility, as it is a newly founded program. Until such tests are addressed, as well as the limitations and gaps in knowledge mentioned above, it is inaccurate to claim that IE is a science, as its website currently does. The literature review presented here suggests that IE offers some well-supported tools and advice for systematic product innovation, but also that IE must stay innovative itself and incorporate the most current research in order to deliver benefit to its customers.

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