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Introduction

Creativity is the capacity of an individual or organization to conduct effective ideation, and create new inventions, solutions to issues, problems, or provision of new capabilities. If/when inventions become effective in the marketplace, they are termed innovations. These creativity, ideation, invention and innovation, CI3, processes, capabilities, and results constitute the requisite ingredients to successfully transit from the identification of an issue, shortfall, or opportunity to a successful product in the marketplace. “The creative process, generating new ideas, information, and knowledge, drives innovation and development” [ref. 1]. As we leave the Industrial Age and enter the Virtual Age, we are switching from major wealth creation via extraction of natural resources to wealth creation via inventing things and providing new capabilities. “84% of executives say future success is dependent upon innovation” [ref. 2]. Successful innovations can increase productivity, enable new products and services, and provide a competitive advantage. Innovation is the prerequisite for economic development. “The economics of the 21st century will be characterized by knowledge, information, and innovation” [ref. 1]. The components of the innovation CI3 chain are increasingly readily available worldwide as a result of the IT revolution, including the vastly improved communications and knowledge access provided by the web. As Friedman [ref. 3] wrote in circa ’05, the world is essentially flat in regard to technology. Therefore, the competition to produce innovative solution spaces and innovations is increasingly keen. The combination of the data/knowledge on the web for ideation/invention/innovation and the development of printing manufacture is producing a planet of inventors/invention.

It is therefore of interest and perhaps essential to consider and optimize the conditions conducive for/to the CI3 chain, from problem/issue/opportunity to marketing of a successful new product/service (including the requisite characteristics of a creative culture). Also of interest is the increasing impacts of digitization upon CI3 including the ongoing development of machine ideation/computational creativity, data analytics and intelligent agents, as well as the optimization of the innovation development process. In general, what is required with regard to knowledgeability for successful CI3 is competitive intelligence, market intelligence, applications intelligence, and technological intelligence.

Conditions Conducive to CI3

As discussed herein, ideation is now the province of both humans and machines. Both employ similar approaches which includes the input into the human “subconscious”/machine of extensive facts/data or information which the subconscious/machine attempts to juxtapose, process in multitudinous ways to produce potential solution approaches. These are then evaluated in what is essentially a systems level optimization process. When the subconscious appears to find/discover a combination that might be suitable, it reports this to the conscious. It does this when (for humans) it is not first order occupied, showering, shaving, upon first awakening, during the night, etc. Most often for humans these ideas occur away from the site of and after actual work on the problem, after the subconscious has mulled over the inputs and the nature of the problem and related details [ref. 4].

The basis of successful ideation is knowledgeability regarding all aspects of the problem including importance, nature, metrics, benefits if solved, applicable engineering ilities, technologies, and econometrics. The information required for knowledgeability is now far more readily available at far more coverage and detail than was the case in the days of libraries vice the web in the last century. Additional requisite knowledgeability includes any previous solution approaches to related problems, or to a similar problem but for which the markets or required technologies were not available but may now be. Thus, step one in the ideation/invention process is wide spectrum knowledgeability. Step two is the assembly from knowledge collection of previous solution attempts if any, and personal/group ideation, via the human brain or machine brains. A longish number of putative solution spaces is desirable because few initial ideas actually become innovations after triage. This occurs for many reasons as will be discussed under "second filter issues". Once the set of previous and ab initio solution possibilities is assembled, the next steps are evaluative, the scientific method, triage to determine their suitability as inventions and ultimately innovations, and solving real problems/shortfalls in the real world with real world metrics.

The elements conducive to creativity include masses of information/data/facts, (aka knowledgeability), a well-defined problem, along with a tolerance for failure, which is endemic to the ideation process. Additionally required is perseverance, perhaps the most critical attribute of an inventor. It is interesting that in a number of instances solution spaces are available via redefining the problem based upon the core requirement(s). This approach has sometimes been termed as both raising the bridge and lowering the river, vice just raising the bridge. Sometimes only lowering the river is necessary. Systems level analysis is useful for such problem redefinition.

The characteristics of creative organizations/individuals are in many cases different from the conventional. A common term for such deviation is mavericks. The commonly cited creativity attributes include excited, independent, spontaneous, experimental, can be subversive, rebellious, impertinent, courageous, self-reliant, iconoclastic, argumentative, challenging, questioning, playful, confident, curious, non-conforming with wide interests/knowledgeability, with a tolerance for ambiguity, and a preference for complexity [e.g., ref. 5]. Humans tend to be uncomfortable with change, partially due to the amygdala, the part of our brain which tends to keep us conservative, and inventors innovators/mavericks are endemic change agents. Studies indicate almost all children are very imaginative when entering kindergarten. By second grade this imaginative nature in students diminishes. The regimentation in the traditional classroom appears to be responsible for this change [e.g., ref. 6]. Therefore, early on the number of individuals with the aforementioned creative, independent, "maverick" characteristics is a small percentage of the population. This needs to change. Society needs to be far more conducive to maverickism now due to the increasingly major societal and economic importance of innovation with regard to wealth creation.

There are several ways to garner CI3 from those that possess such. Delphi, asking informed others, is one such way. Others include "brain storming" (which many studies look askance at) [ref. 7]. The best brainstorming appears to occur when the ideation effort(s) are conducted pre-meeting and the meeting is more of an evaluation and initial triage. With digitization, open innovation/crowd sourcing has become popular. This can have intellectual property protection issues. The other major developing alternative to human ideation is machine ideation, discussed in a subsequent section. Then there are multiple approaches for idea evaluation/triage (including mod-sim) at the detailed design and system levels. A value web of highly knowledgeable, experienced personal contacts worldwide if available can supply an initial "read" with regard to feasibility and potential value.

There are several useful precepts for successful ideation. These include a major effort to understand all aspects of the problem. Also, it is important to emphasize/select for evaluation 'big ideas" or solution spaces with large benefits. This is important because as the evaluation process proceeds, more real-world considerations are included, and usually the benefits decrease. Large performance margins are needed when the evaluation process begins. It is important to question everything, including conventional wisdom and assumptions, and it is sometimes useful to obviate the assumptions as a goad to diversity of conceptualization. Inviting others, including mavericks to contribute/critique can be valuable, as they often perceive things differently and have rich imaginations. Mavericks are non-conforming - difficult to “manage,” but very easy to lead [ref. 8].

Knowledgeability Approaches:

- Periodic preparation of review papers
- Perusal of large numbers of the free daily tech advancement reporting/abstracting sites (many tens of sites available)
- Intelligent search agents to continually search and evaluate tech arenas, informed by personal proclivities, 24/7/365
- Superb report reference lists including foreign works (some 75% of research now offshore)
- Conduct/document literature review before beginning a project
- Motivate/incite curiosity as a way of life
- Establish/continually feed an organizational unique “knowledge base” (trip reports, program charts, ideas that occur, things learned/heard, organizational “yellow pages,” etc.)
- Measure/reward knowledgeability
- Search the patent literature worldwide
- Utilize commercial tech update/ evaluation services

Machine/Computational Creativity

Machine assisted human creativity began decades ago initially via the availability of an ever-increasing magnitude of information on the web and the search engines to access such. As artificial intelligence (AI) has developed, there has been progress on “intelligent search agents” which, after being instructed on what is of interest, or via monitoring user search patterns/content, can summarize and increasingly analyze web content for the human user. There are several approaches to creativity triggers [TRIZ [ref. 9], SCAMPER [ref. 10], STRATEGYN [ref. 11]]. There are also long lists of ways to incite an altered approach to thinking about the problem and potential solution spaces.

What is now evolving is actual machine creativity [refs. 12, 13]. Problems are posed by humans, or can be sent from machines, and the machines create and can increasingly triage solution spaces. The basic enabler is evolutionary algorithms. Thaler was an early applier with his imagination engine/creativity machine [ref. 14]. His approach was to train a neural net and then deprive it of rational input. The neural net was observed to dream, apparently much like humans dream, and in the process produce new combinatorials. These were then evaluated at the systems level for application to various problems and metrics. This fundamental approach to machine ideation has been quite successful over the years, producing new capabilities and products. Thaler has updated his approach (which he termed DABUS). and he now combines and enriches combinatorials. These combinatorials are then filtered, and those selected as interesting undergo post processing, moving the processes up the complexity, and solution richness chain.

The process of generating multitudes of applicable combinatorials is analogous to the human ideation process where after inputting information into the subconscious, it is conjectured that it tries various combinatorials and reports back to the conscious regarding those that it evaluates as useful. The machines have now greatly exceeded human brain speed, (and their knowledge, the amount of information from the web, the emerging global sensor grid, etc.) far exceeds that absorbed by individual humans. As an example, in the time it takes to type a google query, the machines report back millions of “hits”.

This machine ideation is not AI per se; it is basically brute force machine speed and storage capabilities with systems evaluation software applied to forming and evaluating huge numbers of quasi random combinatorials. It will improve as the machines become faster and the information stored/available increases even more. Creativity/ideation is touted as the last bastion of unique human capabilities in regard to machines taking jobs. The actual situation appears to be that is not the case. Machines will be capable of more effective creativity/ideation going forward [ref. 13].

There are several related machine ideation approaches, Thalers creativity machine, one by Koza/Genetic algorithms [e.g., 15], and the now very successful Generative Adversarial Networks (GANS) [ref. 16]. There is a mid-spectrum/alternative machine ideation capability called data analytics which ideates by inference from data, extracting trends and producing projections.

The Innovation Process

Having generated a sizable list of new and old and borrowed solution spaces (aka ideas), the next item of business is to evaluate and triage them for efficacy in the real world. The historical industrial experience is that some 3,000 ideas are required to yield a single viable new product in the marketplace. This is after several triage/evaluation cycles and homework efforts. Simplistically, the ideas have to successfully pass through two filters. The first filter, which in general terms only eliminates some 5%, evaluates whether the ideas are sound technically. The critical second filter, where over 90+% of the elimination occurs, evaluates whether the idea will be successful in the real world and deals with the real world, practical issues and metrics. There are three major categories of issues evaluated in the second filter: engineering, econometrics and legal/regulatory/safety.

Select Engineering Innovation 2nd Filter Issues (Aerospace)

- Producibility, Manufacturability, Maintainability, Reliability, Flyability/Robustness, Inspectability, Performance, Flexibility, Repairability, Operability, Durability/Damage Tolerance, and Infrastructure Compatibility
- The Competition

Select Economic, Business, Innovation 2nd Filter Issues (Aerospace)

- Profit, Costs, Fuel Use, Size/Weight, Part Count, Material, Complexity, Ancillary Effects, Market Timeliness, Protectability/Ease of Duplication, Exclusive Rights/Patents, Novelty, Risk, Distribution System, Availability of Constituents, Productivity, Market Size, and Affordability
- The Competition

Select Safety, Environmental, Legal Innovation 2nd Filter Issues (Aerospace)

- Regulatory Strictures, Crashworthiness, Vortex Hazard, Weather Issues, Emissions, Stall/Spin, Fatigue, Acoustics
- Safety Writ Large

Each of these many issues has a pull down menu of sub issues. If the invention does not pass muster with regard to the applicable issues on these 2nd filter real world lists plus sub issues, and if there is a lack of applicable get well approaches, then the invention, although providing useful performance and benefits, is sidelined. The myriad second filter issues are the major reason why a large number of inventions are needed to provide what ends up being a small number of successful “products”/innovations. A major reason why so many concepts/approaches/solution spaces do not satisfy the second filter strictures is primarily because initially the inventors are not sufficiently knowledgeable in regard to these real world second filter issues and therefore do not carry the research and evaluation of the idea far enough, nor address the complete set of application metrics. As the idea goes through the TRL evaluation ladder, the entire applicable second filter set of issues needs to be considered from the beginning of the ideation process. The second filter issues, particularized to the problem being addressed, is part of the definition of the problem, and need to be researched, assembled and considered as soon as possible in the TRL evaluation process.

For commercial innovation, the content and details with regard to the second filter issues are often proprietary. They are typically not taught in academia, although the increasing utilization of “professors of practice”, generally very experienced industrial, application engineers, are bringing second filter knowledgeability into the curriculum somewhat. Otherwise, researchers/inventors will need to work/partner with industry to obtain the requisite second filter knowledgeability. Including 2nd filter issues at the beginning or ideation stage of the development of an innovation should drastically improve the efficiency and lower the cost/shorten the time for attainment of a successful innovation, resulting in something(s) successful in the marketplace.

Increasingly, as machines and mod-sim software improve in speed and capability, the idea evaluation process is shortening and becoming less costly. However, both mod-sim and physical experiments for concept evaluation require appropriate initial and boundary conditions, which for some problem solution spaces are critical piece parts of the problem definition and can be difficult to definitize. The inclusion of the second filter issues, both their detailed specification and inclusion in the evaluation process, could lengthen the evaluation time/cost. However, this should be more than compensated for by the much timelier development of a viable innovation via far fewer and often costly dead ends or cul-de-sacs.

Takeaways:

- We are in the midst of unprecedented technology revolution(s) with massive impacts upon nearly every aspect of human lifestyles and economics including education.
- The new basis of wealth is products and processes produced via, by CI3.
- Invention will be increasingly supplied by a combination of augmented human brains and machine intelligence.
- There are nascent breakthroughs in just about every technical arena (e.g., materials, energetics, computing, sensors, synthetic biology, etc.) which should transform civilization going forward.

There are two stages to developing an innovation: 1) the ideation, imagineering stage where significant effort is first required to define the problem well in all aspects and to acquire the requisite massive applicable knowledgeability, followed by imagineering/ideation of potential multiple solution spaces, and 2) evaluation, using real world metrics/2nd filter issues, of the posited multiple possible innovations. This again requires significant effort.

- Divergent thinking is required to ideate and should question everything, continually learning from any source.

- Concentrate on concepts, solution spaces with large margins, as the real world second filter issues usually increase time, weight, cost, etc.

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