Chapter 3: Invention and Innovation

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You will learn four simple tools to turn inventions into innovations:

1. Link and foster relationships between inventors and innovators. Invention and innovation require different skills rarely found in the same person.
2. Don't ignore "trivial" advances. Major innovations often have small, but profitable beginnings, and then are extended to other fields.
3. Be aware of movements that drive consumer interest due to social change, demographics, and contagion.
4. Know every benefit that consumers derive from your products or services, even small, seemingly insignificant ones, and extend these benefits to new advances.

The economist Schumpeter remarked in 1934:

Economic leadership in particular must be distinguished from invention. As long as they are not carried into practice, inventions are economically irrelevant. To carry an improvement into effect is a task entirely different from the inventing of it, and a task, moreover, requiring entirely different kinds of aptitudes. Although entrepreneurs of course may be inventors just as they may be capitalists, they are inventors not by nature of their function but by coincidence and vice versa. (as cited in Scherer 1984)

Invention and Innovation

The first person to make a novel and prospectively useful product or process is an *inventor* and the first person or enterprise to exploit that invention in a commercially viable product or service is an *innovator*. Anyone who has ever conceived a new product or service and then convinced others to purchase or adopt it will recognize the very different skills required for these two phases of a successful introduction. It is quite rare to find the aptitudes required to invent something and to commercialize it in the same person. In order to explore the separate roles that distinguish invention from innovation, it is worth reviewing some significant historical cases.

The Steam Engine: Watt and Boulton (Scherer 1984)

According to his own account, in an afternoon in the winter of 1764–1765, James Watt, the mathematical instrument maker to Glasgow University, strolled around the grounds to work out a problem. Earlier he had been given a Newcomen engine to repair, a type of engine invented in 1712. During his walk he became conscious of a change that would significantly improve the efficiency of the machine by using a separate condensing vessel. Apparently, the time it took for him to come up with this concept was very short – a matter of hours – and it was dwarfed by the time it took before his insight led to a workable machine in 1780. He may not, in that afternoon, have appreciated the future contributions of John Roebuck, who went bankrupt, and then Matthew Boulton, who played the roles of unsuccessful and successful innovators, respectively. In the development of the Watt-Boulton steam engine neither of them could have seen that their machine would be the overture to the Industrial Revolution when large industrial cities were built far from rivers, reducing reliance on hydropower. By way of contrast to the real potential of their technology, Watt and particularly Boulton were focused on solving a contemporary problem with business potential – getting water out of flooded copper mines.

Two lessons derive from the steam engine story. The first is that the skills of both participants were required. James Watt provided the technical knowledge and the motivation to create a technical improvement and Matthew Boulton encouraged and funded Watt through years of development and resolved a serious patent roadblock. By 1780 they had a commercial product. The second lesson is that many successful products or services extend far beyond the vision of their creators but they all must have at least one sustainable application to get them started, such as extending the life of flooded mines.

Nike: Bowerman and Knight (Moore 2006)

Bill Bowerman, coach of the University of Oregon track team, is known for producing numerous Olympic champions and world record holders, as well as cofounding Nike. Bowerman liked to make running shoes for his athletes as he was dissatisfied with shoe design in the 1960s and early 1970s. He founded Blue Ribbon Sports (BRS) with Phil Knight and they had Bowerman's designs for running shoes manufactured by Onitsuka in Japan. Bowerman, in search of a light shoe with traction for his track athletes, invented a "waffle" sole using a waffle iron in his home. This invention became the basis for the waffle trainer, the first really successful shoe sold by BRS before the company became Nike. When Frank Shorter won the Olympic gold medal for the marathon in Munich in 1972, a running boom was launched in the US. With the running boom came a huge demand from the masses for comfortable shoes suitable for road running. Bowerman's designs were well-suited to exploit that demand.

In this invention–innovation scenario, Phil Knight played the role of Matthew Boulton from the previous case and managed to successfully steer BRS through a contract dispute involving distribution and trademark issues with Onitsuka that could have destroyed the fledgling company.

It is interesting to see once again the expression of the dual aptitudes required in a successful venture. The pattern of initial limited implementation followed by extensibility is seen again as Bowerman's interests were initially focused on the needs of high-performance athletes. The opportunity for mass marketing and expansion into adjacent businesses was successfully exploited by Nike.

The US Navy: Scott and Sims (Tushman and Moore 1982)

Prior to 1898, gunnery accuracy at sea was dismal. In the space of six years, accuracy was increased by 3000% based on the ingenuity and doggedness of two men, Sir Percy Scott of the British Navy and William Sims, an American naval officer.

Scott provided the basis for a process of continuous aim firing by adjusting guns on ships so that gunners could rapidly alter the positioning of guns to compensate for the roll of the ship. He also made changes to the telescopic sight so that gunners could continually sight their targets. Scott made these improvements in 1898 and began recording remarkable gunnery records. In 1900, Scott met Sims and showed him his new technique. Before long, Sims began to demonstrate similar improvements in gunnery accuracy to Scott. Then he set out to educate the US Navy who would surely welcome this new advance with open arms. On the contrary, they set out to prove that it was physically impossible to produce the results that Sims produced. He was dismissed and regarded as a falsifier of evidence. In a highly unusual move for a naval officer, Sims wrote to President Roosevelt to express his conviction about the value of continuous aim firing and in 1902 he was made Inspector of Target Practice. Scott's method was finally adopted by the US Navy over a period of about six years.

Continuous aim firing was a process made up of components brought together by Percy Scott, none of which he invented individually – guns, gears, telescopic sights – but he put them together in a highly successful way. William Sims, possessed of a desire to revolt against the rigidity of the status quo, provided the commitment and passion to bring Scott's process into use. This case illustrates again the dual aptitudes mentioned already but also demonstrates the role of chance in bringing innovative components together. We also see the resistance to change in any society where the people in it have limited identifications. In the Navy at that time, gunners were not influential due to the ineffectiveness of their craft and others in that society, such as other naval officers who were responsible for the strategic location of ships in battle, were not readily stepping forward to relinquish their power when gunners started to actually hit their targets. In a hopeful attempt to address the issue of limited identifications, Morison suggested:

> *Any group might begin by defining for itself its grand object and see to it that everyone understands what it is. (as cited in Tushman and Moore 1982)*

If one wants to create an innovative organization of a few people or of thousands, it is worthwhile to consider the aptitudes in staffing that would be required. Innovation is a messy, disruptive business often accompanied by personalities to match these qualities. In many companies, great ideas and concepts may be languishing for the attention of a Boulton, Knight, or Sims. Some inventions may not be seen as grand enough to warrant interest. This attitude misses the point that small-scale but profitable implementation may be all that is needed at first before the landslide of another industrial revolution, a worldwide fitness boom, or an upheaval in a structured society, such as the Navy.

Consumer-Perceived Benefits: Coffee, Beer and Cigarettes

Inherent in the earlier definitions of invention and innovation is that an innovation provides a benefit to its user, one not obvious in current practice. In the steam engine case, the benefit was extended mining; in the Nike case, the benefit was improved athletic performance and consumer-perceived injury protection; in the continuous aim firing case, the benefit was hitting targets more accurately. In the case of consumer products, some of which have deleterious health effects, an important consideration is that these benefits are consumer-perceived.

By the early 1970s Philip Morris had acquired the Miller Brewing Company. By the middle of that decade two products were introduced that had a major impact on their industries. One was Miller Lite and the other was a cigarette called Merit. Both of these brands were based on remarkably similar consumer-perceived benefits. In the case of Miller Lite a technical advance in brewing technology allowed the introduction of a product with extremely low carbohydrate content without sacrificing taste. Merit advertising promoted cigarette flavor equal to full flavor rivals at half the tar, made possible through the use of a novel advance in tobacco flavor technology. Tar reduction may imply a health benefit from the consumer's perspective. These two products contributed to new categories that became as important to their companies' revenues as the original categories.

The introduction of the Merit cigarette brand was not the first time that perceived health benefits drove fortunes in the tobacco industry. After Louis Pasteur connected disease to microbes in the 1860s, there was a lag until the general public became aware of the germ theory of disease in the 1880s. The spread of tuberculosis from sputum became a common concern and with it the health implications of chewing tobacco, the dominant form of tobacco use in the US in the 19^{th} century. Smoking forms, such as pipes and cigars, began to increase as chewing tobacco declined, and in 1910, the future of the tobacco industry appeared to be firmly hooked on smoking (or pipe) tobacco. Then in 1913 the whole industry abruptly changed when R.J. Reynolds blended Bright and Burley tobacco to make a suitable inhalation form to create modern cigarettes. Lung absorption of nicotine and delivery to the bloodstream is far more efficient than buccal absorption as occurs with chewing tobacco. Ironically, a consumer health issue ignited consumers to turn to cigarettes and away from chewing tobacco, which they perceived to be an unhealthy alternative. This is the benefit that resonated with consumers and led to the creation of a multi-billion dollar industry.

The Merit/Miller Lite scenario seemed ripe for a repeat after Philip Morris acquired General Foods in the 1980s. Technology for removing caffeine from coffee using a CO_2 extraction process seemed appropriate to take nicotine out of cigarettes to simulate what had been done with decaffeinated coffee. A product with little or no nicotine was test marketed in the late 80s under the brand name "Next". This product was a failure and a valuable lesson for those who supported it in the company because it underscored the importance of understanding what a company's products provide to consumers. The analogy with coffee was unfortunate and a better comparison might have been to whiskey where the removal of alcohol would leave behind a straw-colored uninteresting beverage or even lightly flavored water in the case of vodka. At least decaffeinated coffee is still a warm, good tasting beverage with consumer-perceived benefits. In removing nicotine from cigarettes, the main psychoactive substance that drives cigarette consumption was removed and there also may have been important sensory effects due to nicotine that disappeared on extraction.

Extensibility: Is There a Limit to it?

The steam engine extended to many industries and the waffle sole attracted non-elites; does extensibility always follow a successful innovation? Limits to the idea of extensibility can show up in surprising places. Statistical tools such as the general linear model may be properly called innovations as they have reached large scale successful introductions. A relatively recent development, the generalized linear model (McCullagh and Nelder 1989), allows the exploitation of the mathematical machinery for fitting the linear model to a broad range of other models through the specification of a link function. Although these statistical innovations have been very successfully employed in many fields, they have limitations in product and concept testing because their assumptions do not account for the psychological processes involved in quantifying features or attributes that differentiate products.

Just as the cigarette brand Next challenged the limits of extending an idea from one category (coffee) to another (cigarettes), so too there are limits to how far we can exploit models from statistics and apply them to human decision-making. A simple example of the limitations of a classical model of binary choice is when a subject chooses the item of greatest intensity from two alternatives as opposed to choosing one of two alternatives that is most similar to one of the alternatives acting as a reference. Both of these methods involve binary choice and theoretical results from the binomial distribution are often used to conduct hypothesis tests on the data. However, without specifying a psychological process for each of these methods, there is no hope of ever relating them to each other or of finding a common framework for interpreting the results. For this we need a theory that allows us to scale sensory intensities and thus conventional statistical models are blocked from making progress in understanding observations without considering how people make decisions.

Innovation in Scaling Intensities and Emotions

Consumer-perceived benefits, whether justified or not, can drive major changes in the fortunes of companies and even create new businesses. Next we will examine the product and concept testing field to identify benefits that are linked to current and developing models. Consumers of research on products and concepts have certain basic needs and they judge the benefits provided by the methods and models used according to their ability to satisfy those needs.

These consumers have two general interests. One is to measure features that differentiate among products and the other is to reach an understanding of why people like or choose certain products or brands. These interests are discussed in the next sections on scaling intensities and emotions.

Scaling Intensities

According to legend, Gustav Fechner, a physicist, lay late in bed on the morning of October 22, 1850 contemplating a log-law relationship between physical and mental quantities to explain known data. His conception that morning gave birth to the field of psychophysics in which theories concerning the relationship between the physical world and its mental representation are nurtured. Every year, October 22 is celebrated as "Fechner Day" around the world by Fechnerian psychophysicists and the festivities include a special conference by the International Society of Psychophysicists. It is doubtful that their excitement will ever create a civil disturbance or compete with the Carnival in Rio de Janeiro. Nevertheless, for this small group of followers, Fechner made a scientific advance in psychological scaling that affected the thinking of all students of mental processes. Commercial applications of functions linking physical quantities, such as the time it takes for a gallon of water to exit a drain, to their mental representations, such as the perceived elapsed time, abound in consumer product categories. Physicochemical measures validated by psychophysical techniques reduce the cost and time of product development and improve the quality of consumer products.

There are items for which a clear physicochemical correlate is not obvious, such as the beauty of art or handwriting specimens, and yet we still would like to produce relative scale values. In some cases the perceptual scale values are multivariate and it is of value to quantify and relate these multiple features, even though we are not aware of the physical or chemical correlates. In the consumer products area, an example might be the quality of a fine fragrance.

In 1927, Louis L. Thurstone published a basis for a "purely" psychological theory for scaling that met this need. His papers from this period led to what are known today as Thurstonian probabilistic models. These models specify two basic ideas – the information and cognitive processes leading to decisions are probabilistic and there is a definable decision rule that depends on task instructions. In many cases the decision rule is deterministic (same information – same response) but some models allow a probabilistic decision rule (the response is known only with a certain probability). Thurstone was mainly concerned with the former type of decision rule, although the latter is a reasonable extension.

The development of Thurstonian models has been extensive and there is now a large family of models that account for the results of many different types of behavioral tasks. Table 1 is a partial list of the methods for which Thurstonian models have been developed with associated references. Thurstonian models have very compelling process assumptions regarding the distribution of perceptual intensities and the decision rules applicable to each method to which they have been applied. They provide a theoretical framework for relating the results of product testing methods to one another so that the relative power of the methods can be compared (Ennis 1993). They are very well-suited to accommodate multivariate attributes of items with a simple structure to account for different variances and covariances (Ennis and Johnson, 1993).

In the cases of invention and innovation discussed earlier, the separate roles of inventor and innovator were connected to individuals. Inevitably, this simplification diminishes the role of many other players in any major innovation. In the case of Thurstonian scaling, it could be thought that Thurstone's inventions were popularized and, in some cases commercialized, not by one innovator but by a community of scientists and programmers who contributed to the dissemination of useful tools. These tools were then used to bring Thurstonian scaling to those who would benefit from them.

Scaling Emotions (Hedonics)

Let us turn now from scaling intensities, which was the first interest mentioned in the previous section, to models of hedonicity, including liking and preference, for instance. It is quite natural when thinking of an hedonic response to consider it to be based on an hedonic continuum like we would a sensory variable such as sweetness. This idea is a direct extension of the previous section. Thinking of liking or preference responses as arising from judgments based on an hedonic or utility scale makes it possible to consider using Thurstonian models. Then to find explanatory variables for this hedonic scale, one could use a linear combination of explanatory variables. A more imaginative alternative is to consider that scaling emotional responses involves considering the possibility of individual internally generated points which are used to make liking or preference decisions. Sometimes these points are referred to as ideal points or motivation points.

The distribution of perceptual intensities is assumed to be normal in Thurstonian models. The justification for the normality assumption is that perceptual intensities result from the aggregated effect of millions of receptors activating a myriad of neurons. According to the central limit theorem, means arising from such an averaging process will tend to be normally distributed with increasing sample size.

If, instead of assuming that perceptual intensities are distributed normally, we assume that they are distributed according to a double exponential distribution, then a simplification occurs. Differences in these random variables follow a logistic distribution, which has a closed form, assuming that the perceptual intensities are independent. This benefit of a simple, more computationally efficient model looms large when choices are made among multiple alternatives, an issue of importance in marketing and economics. A Thurstonian model of this task rapidly becomes computationally expensive compared to a logit model which remains in closed form. This benefit, notwithstanding other limitations which are overcome in a Thurstonian framework, propelled the logit to become a major innovation in a number of fields including economics, marketing and public health. As sometimes happens in the design of technologies, the design that becomes the generally adopted and celebrated innovation is the one that works best at low cost, efficiently, 24/7. A choice model based on the logit is such an innovation. Contributors to choice models such as the logit and its applications include Daniel McFadden who was awarded the Nobel Prize in Economics in 2000 and R. Duncan Luce who was awarded the 2003 National Medal of Science for work he completed in 1959. The impact and even the source of innovations can take decades or even centuries to be identified. Luce, who was seventy-nine when he received the prize from President Bush, remarked:

> *This is a great honor for which I am most grateful … I'm also grateful for my genes, which have enabled me to live a long life and enjoy this honor.*

An area for future development is the incorporation of ideal point concepts into Thurstonian models. This area offers significant advantages compared to the logit to discover drivers of preference, liking, motivations and other hedonic or emotional responses (Ennis, Rousseau and Ennis, 2011). These benefits are already well recognized and the process of turning Thurstonian ideas in this area into innovations has begun. One example is the use of a closed form Thurstonian similarity model from the previous section to find individual and item locations in a sensory space.

It would be foolish to think that any of the models mentioned in this section, or anywhere else, will not be made utterly irrelevant at some point in the future. All scientific models are fictions, not necessarily extensions of each other, and at any given time the accepted narrative is the one that explains the observables best. With advances now being made in neuroscience, the field of psychology itself will disappear in its present form as we formulate compelling molecular models to answer the question – "what is the chemistry of choice?" When that happens we will have a rather different perspective on the parameters that account for decision making.

Final Remarks

In general, for inventions to blossom into innovations, they usually benefit from the confluence of certain, sometimes chance, characteristics.

- They may coincide with a movement, such as a running boom;
- They may extend to other fields;
- They should have consumer perceived benefits;
- Their commercial value should be recognized and supported by individual or community entrepreneurs;
- They should be easily implemented. Otherwise, they will be interesting but, as Schumpeter remarked, "economically irrelevant."

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Table 1. List of methods and references to corresponding Thurstonian models

Method	References
M-alternative forced choice	Hacher and Ratcliff 1979
Triadic choice	Ennis and Mullen 1986; Ennis and Mullen 1992; Ennis, Mullen and Frijters 1988; Mullen and Ennis 1987
Tetradic Choice	Ennis, Ennis, Yip, and O'Mahony 1998; Rousseau and Ennis 2001; Rousseau and Ennis 2002
Ranks	Böckenholt 1992
Motivations	Ennis and Rousseau 2004
Similarities and proximities	Ennis, 1988; Ennis 1992; Ennis and Johnson 1993; Ennis, Palen, and Mullen 1988; Nosofsky 1988; Shepard 1988; Zinnes and MacKay 1983
Preferential choice	De Soete, Carroll and DeSarbo 1986; Ennis 1993; Ennis and Johnson 1994; MacKay, Easley and Zinnes 1995; Mullen and Ennis 1991; Zinnes and Griggs 1974; Zinnes and MacKay 1987
Liking	Ashby and Ennis 2002
Identification and categorization	Ashby and Gott 1988; Ashby and Lee 1991; Ennis and Ashby 1993