3.3: Generating Ideas

New Product Development

Innovation

Innovation is the creation of better, more effective products, processes, services, or technologies.

Learning Objectives

Subdivide the innovation process in to sources, goals, failures, and diffusion

Key Takeaways

Key Points

- Innovation is defined in this context as the development of better products or services.
- In business and economics, innovation is the catalyst to growth. With rapid advancements in transportation and communications over the past few decades, the old-world concepts of factor endowments and comparative advantage, which focused on an area's unique inputs, are outmoded for today's economy.
- In the organizational context, innovation may be linked to positive changes in efficiency, productivity, quality, competitiveness, market share, and others. All organizations can innovate, including hospitals, universities, and local governments.

Key Terms

- **innovation**: The creation of better or more effective products, processes, services, technologies, or ideas that are not readily available but will soon be.

In business and economics, innovation is the catalyst to growth. With rapid advancements in transportation and communications over the past few decades, the old-world concepts of factor endowments and comparative advantage, which focused on an area's unique inputs, are outmoded for today's global economy.

Organizations

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Sources of Innovation

The famous robotics engineer Joseph F. Engelberger asserts that innovations require only three things: (1) A recognized need; (2) competent people with relevant technology; (3) financial support.

The Kline Chain-linked model of innovation places emphasis on potential market needs as drivers of the innovation process, and describes the complex and often iterative feedback loops between marketing, design, manufacturing, and research and development (R&D). Innovation by businesses is achieved in many ways, with much attention now given to formal research and development for "breakthrough innovations. " R&D helps spur on patents and other scientific innovations that lead to productive growth in such areas as industry, medicine, engineering, and government. Yet, innovations can be developed by less formal on-the-job modifications of practice, through exchange and combination of professional experience and by many other routes. The more radical and revolutionary innovations tend to emerge from R&D, while more incremental innovations may emerge from practice—but there are many exceptions to each of these trends. An important innovation factor includes customers buying products or using services. As a result, firms may incorporate users in focus groups (user-centered approach), work closely with so-called lead users (lead user approach) or users might adapt their products themselves.

Goals and Failures

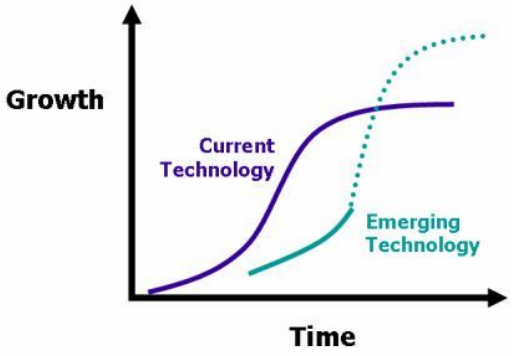
Programs of organizational innovation are typically tightly linked to organizational goals and objectives, to the business plan, and to market competitive positioning. One driver for innovation programs in corporations is to achieve growth objectives. A survey across a large number of manufacturing and services organizations found that systematic programs of organizational innovation are most frequently driven by (ranked in decreasing order of popularity): Improved quality, creation of new markets, extension of the product, range, reduced labor costs, improved production processes, reduced materials, reduced environmental damage, replacement of products/services, reduced energy consumption, and conformance to regulations. These goals vary between

improvements to products, processes and services and dispel a popular myth that innovation deals mainly with new product development. Most of the goals could apply to any organization, be it a manufacturing facility, marketing firm, hospital or local government. Whether innovation goals are successfully achieved depends greatly on the environment prevailing in the firm. Conversely, failure can develop in programs of innovations. The causes of failure have been widely researched and can vary considerably. Some causes will be external to the organization and outside its influence of control while others will be internal and ultimately within the control of the organization. Internal causes of failure can be divided into causes associated with the cultural infrastructure and causes associated with the innovation process itself. Common causes of failure within the innovation process in most organizations can be distilled into five types: (1) Poor goal definition; (2) poor alignment of actions to goals; (3) poor participation in teams; (4) poor monitoring of results; (5) poor communication and access to information.

Diffusion of Innovations

Once innovation occurs, innovations may be spread from the innovator to other individuals and groups. This process has been proposed that the life cycle of innovations can be described using the "S-curve' or diffusion curve. The S-curve maps growth of revenue or productivity against time. In the early stage of a particular innovation, growth is relatively slow as the new product establishes itself. At some point customers begin to demand and the product growth increases more rapidly. New incremental innovations or changes to the product allow growth to continue. Toward the end of its life cycle growth slows and may even begin to decline. In the later stages, no amount of new investment in that product will yield a normal rate of return.

Innovative companies will typically be working on new innovations that will eventually replace older ones. Successive S-curves will come along to replace older ones and continue to drive growth upwards. The S-curve derives from an assumption that new products are likely to have "product life" (i.e. a start-up phase, a rapid increase in revenue and eventual decline). In fact the great majority of innovations never get off the bottom of the curve, and never produce normal returns.



Technological Innovation Chart: In the figure above the first curve shows a current technology. The second shows an emerging technology that currently yields lower growth but will eventually overtake current technology and lead to even greater levels of growth.

New Product Ideas

New product ideas can generate from existing frustrations using a certain product, or a desire to do something better or more simply.

Learning Objectives

Explain the front-end process of new product development (NPD) and the characteristics of a SWOT analysis

Key Takeaways

Key Points

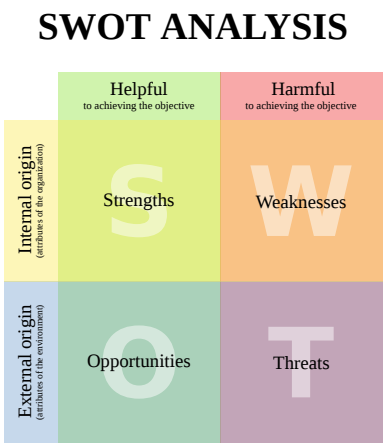
- Most new product ideas come from experiences, like frustrations with an existing product.
- There are two parallel paths involved in the NPD process: one involves the idea generation, product design and detail engineering; the other involves market research and marketing analysis.
- Lots of ideas are generated about the new product. Out of these ideas many are implemented. The ideas are generated in many forms. There are many factors responsible for generation of an idea.

Key Terms

- **SWOT Analysis**: a structured planning method used to evaluate the strengths, weaknesses, opportunities, and threats involved in a project or in a business venture
- **life cycle**: The useful life of a product or system; the developmental history of an individual or group in society.
- **product life cycle**: the stages that a good or service goes through from when it is first introduced to when it is taken off the market

In business and engineering, new product development (NPD) is the complete process of bringing a new product to market. A product is a set of benefits offered for exchange. It can be tangible (something physical you can touch) or intangible (like a service, experience, or belief). There are two parallel paths involved in the NPD process: idea generation, including product design and detail engineering; and market research and marketing analysis. Companies typically see new product development as the first stage in generating and commercializing a new product within the overall strategic process of product life cycle management, used to maintain or grow their market share.

Ideas for new products can be obtained from basic research using SWOT analysis: Strengths, Weaknesses, Opportunities & Threats. Many methods may be used to gain insight into new product lines or product features, including:



SWOT Analysis: Here is an example of the SWOT analysis matrix.

- Market and consumer trends
- Research and development
- Competitors
- Focus groups and trade shows
- Employees and corporate spies
- Salespeople
- Ethnographic discovery methods (searching for user patterns and habits)

Five Different Front-End Elements

1. Opportunity identification: Large or incremental business and technological chances are identified in a relatively structured way. Using the guidelines established here, resources are allocated to new projects, leading to a structured New Product & Process Development or NPPD strategy.
2. Opportunity analysis: This element translates identified opportunities into implications for the business and technology specific context of the company. This element focuses on aligning ideas to target customer groups, and can include market studies and/or technical trials and research.
3. Idea genesis: The evolutionary and iterative process of progressing an initial idea from birth to maturation into a tangible idea. This process can occur internally or externally (e.g., a supplier offering a new material or technology, or a customer presenting an unusual request.
4. Idea selection: The decision to pursue an idea is determined by analyzing its potential business value.
5. Concept and technology development: During this part of the front-end, the business case is developed based on estimates of the total available market, customer needs, investment requirements, competition analysis and project uncertainty. Some

organizations consider this the first stage of the NPPD process

Following a Product Development Process

Product development is idea generation, screening, business analysis, technical development, manufacturing, testing, and commercialization.

Learning Objectives

Outline the several stages in new product development

Key Takeaways

Key Points

- Ideas for new products can be obtained from customers (employing user innovation), the company's research and development department, competitors, focus groups, employees, salespeople, and more.
- The object of idea screening is to eliminate unsound concepts prior to devoting resources to them.
- The focus of the business analysis is primarily on profits, but other considerations, such as social responsibilities, may also be involved.
- Manufacturing planning must consider how to secure the availability of required funds, facilities, and personnel at the intended time, as well as the methods of coordinating this effort.
- Test marketing is the final step before commercialization; the objective is to test all the variabilites in the marketing plan including elements of the product.

Key Terms

- **Focus Group**: A group of people, sampled from a larger population, interviewed in open session for market research or political analysis

New Product Development Process

There are several stages in the new product development process–not always followed in order:

Idea Generation

Generating new product ideas is a creative task that requires a specific way of thinking. Ideas for new products can be obtained from customers (employing user innovation), the company's R&D department, competitors, focus groups, employees, sales people, corporate spies, trade shows, or through a policy of Open Innovation. Formal idea generating techniques include attribute listing, forced relationships, brainstorming, morphological analysis, and problem analysis.

Idea Screening

The second step in the product development process is screening. It is a critical part of the development activity. The object is to eliminate unsound concepts prior to devoting resources to them. The screeners must ask at least three questions:

1. Will the customer in the target market benefit from the product?
2. Is it technically feasible to manufacture the product?
3. Will the product be profitable when manufactured and delivered to the customer at the target price ?

Business Analysis

After the various product ideas survive their initial screening, very few viable proposals will remain. Before the development of prototypes can be decided upon, however, a further evaluation will be conducted to gather additional information on these remaining ideas in order to justify the enormous costs required. The focus of the business analysis is primarily on profits, but other considerations, such as social responsibilities, may also be involved. Management must:

- Estimate the likely selling price based upon competition and customer feedback.
- Estimate sales volume based upon size of market.
- Estimate profitability and the break even point.

Technical and Marketing Development

A product that has passed the screening and business analysis stages is ready for technical and marketing development. Technical development involves two steps. The first is the applied laboratory research required to develop exact product specifications.The goal of this research is to construct a prototype model of the product that can be subjected to further study. Once the prototype has been created, manufacturing-methods research can be undertaken to plan the best way of making the product in commercial quantities under normal manufacturing conditions. This is an extremely important step, because there is a significant distinction between what an engineer can assemble in a laboratory and what a factory worker can produce.

Prototypes: One step in the product development process is technical development.

While the laboratory technicians are working on the prototype, the marketing department is responsible for testing the new product with its intended consumers and developing the other elements of the marketing mix. They must ask the following questions:

1. Who is the target market, and who is the decision maker in the purchasing process?
2. What product features must the product incorporate?
3. What benefits will the product provide?
4. How will consumers react to the product?
5. How will the product be produced most cost effectively?
6. What will it cost to produce it?

Marketers must then prove feasibility through a virtual computer-aided rendering and rapid prototyping, and test the concept by asking a sample of prospective customers what they think of the idea.

Manufacturing Planning

Assuming that the product has cleared the technical and marketing development stage, the manufacturing department is asked to prepare plans for producing it. The plan begins with an appraisal of the existing production plant and the necessary tooling required to achieve the most economical production. Compromise between attractiveness and economy is often necessary. Finally, manufacturing planning must consider how to secure the availability of required funds, facilities, and personnel at the intended time, as well as the methods of coordinating this effort.

Marketing Planning

It is at this point that the product planner must prepare a complete marketing plan–one that starts with a statement of objectives and ends with the fusion of product, distribution, promotion, and pricing into an integrated program of marketing action.

Test Marketing

Test marketing is the final step before commercialization; the objective is to test all the variabilites in the marketing plan including elements of the product.

Commercialization (often considered post-NPD)

At last, the product is ready to go. It has survived the development process, and it is now on the way to commercial success. How can it be guided to that marketing success? It is the purpose of the lifecycle marketing plan to answer this question. Such a complete marketing program will, of course, involve additional decisions about distribution, promotion, and pricing.

Screening

Idea screening attempts to eliminate unsound product concepts prior to devoting resources to them.

Learning Objectives

Explain how product developers use a simple checklist and assign weights of importance in order to best screen ideas

Key Takeaways

Key Points

- If a poor product idea is allowed to pass the screening state, it wastes effort and money in subsequent stages until it is later abandoned. However, the possibility of screening out a worthwhile idea is even more serious.
- The first technique of screening is a simple checklist. For example, new product ideas can be rated on a scale ranging from very good to poor.
- A second technique goes beyond the first, in which criteria are assigned importance weights, with products rated on a point scale measuring product compatibility.
- New product criteria include value added, sales volume, patent protection and affect on present products.

Key Terms

- **patent**: A declaration issued by a government agency declaring someone the inventor of a new invention and having the privilege of stopping others from making, using or selling the claimed invention; a letter patent.
- **idea screening**: the process of testing concepts and eliminating unsound ones

Idea screening is an early step in the new product development process and is a critical part of the development activity. If a poor product idea is allowed to pass the screening state, it wastes effort and money in subsequent stages until it is later abandoned. However, the possibility of screening out a worthwhile idea is even more serious, There are two common techniques for screening new product ideas. Both involve the comparison of a potential product idea against criteria of acceptable new products.

The first technique is a simple checklist. For example, new product ideas can be rated on a scale ranging from very good to poor by such criteria as value added, sales volume, patent protection and affect on present products. Unfortunately, it is quite difficult for raters to define what is fair or poor. In addition, the rating system does not address the issue of the time and expense associated with each idea, nor does it instruct with regard to scores. A second technique goes beyond the first, in which criteria are assigned importance weights, with products rated on a point scale measuring product compatibility. These scores are then multiplied by their respective weights and added to yield a total score for the new product idea.

In summary:

The object is to eliminate unsound concepts prior to devoting resources to them.

The screeners should ask several questions:

1. Will the customer in the target market benefit from the product?
2. What is the size and growth forecast of the market segment / target market?
3. What is the current or expected competitive pressure for the product idea?
4. What are the industry sales and market trends the product idea is based on?
5. Is it technically feasible to manufacture the product?
6. Will the product be profitable when manufactured and delivered to the customer at the target price?

Product Screening: Before introducing the iPad to market, Apple had to go through a process of screening in order to conclude the new product would be a worthwhile investment.

Analysis

The focus of the business analysis is primarily on profits, but other considerations such as social responsibilities may also be involved.

Learning Objectives

Explain the business analysis stage of new product development

Key Takeaways

Key Points

- Before the development of prototypes can be decided upon, a further evaluation will be conducted to gather additional information on these remaining ideas in order to justify the enormous costs.
- The first step in the business analysis is to examine the projected demand. This would include two major sources of revenue: The sales of the product and the sales or license of the technology developed for or generated as a by-product of the given product.
- A complete cost appraisal is also necessary as a part of the business analysis.
- The Fourt-Woodlock equation is a market research tool to describe the total volume of consumer product purchases per year based on households which initially make trial purchases of the product and those households which make a repeat purchase within the first year.

Key Terms

- **learning curve**: An experience or graphic representation of progress in learning measured against the time required to achieve mastery of something.
- **economies of scale**: The characteristics of a production process in which an increase in the scale of the firm causes a decrease in the long-run average cost of each unit.

After the various product ideas survive their initial screen, very few viable proposals will remain. Before the development of prototypes can be decided upon, however, a further evaluation will be conducted to gather additional information on these remaining ideas in order to justify the enormous costs. The focus of the business analysis is primarily on profits, but other considerations such as social responsibilities may also be involved. The first step in the business analysis is to examine the projected demand. This would include two major sources of revenue: The sales of the product and the sales or license of the technology developed for or generated as a by-product of the given product. A complete cost appraisal is also necessary as a part of the business analysis. It is difficult to anticipate all the costs that will be involved in product development, but the following cost items are typical:

- Expected development cost, including both technical and marketing research and development.
- Expected set-up costs. These can include production, manufacturing equipment, distribution, etc.
- Operating costs that account for possible economies of scale and learning curves.
- Marketing costs, especially promotion and distribution.
- Management costs.

Other necessary steps in business analysis include:

- Estimating the likely selling price based upon competition and customer feedback.
- Estimating sales volume based upon the size of the target market and such tools as the Fourt-Woodlock equation.
- Estimating profitability and the break-even point.

The Fourt-Woodlock equation is a market research tool to describe the total volume of consumer product purchases per year based on households which initially make trial purchases of the product and those households which make a repeat purchase within the first year. Since it includes the effects of initial trial and repeat rates, the equation is useful in new product development.

$$V = (HH \cdot TR \cdot TU) + (HH \cdot TR \cdot MR \cdot RR \cdot RU)$$

The Fourt-Woodlock Equation: The left-hand-side of the equation is the volume of purchases per unit time (usually taken to be one year). On the right-hand-side, the first parentheses describes trial volume, and the second describes repeat volume. HH is the total number of households in the geographic area of projection, and TR ("trial rate") is the percentage of those households which will purchase the product for the first time in a given time period. TU ("trial units") is the number of units purchased on this first purchase occasion. MR is "measured repeat," or the percentage of those who tried the product who will purchase it at least one more time within the first year of the product's launch. RR is the repeats per repeater (the number of repeat purchases within that same year). RU is the number of repeat units purchased on each repeat event.

Testing

The objective of testing is to test all the variabilites in the marketing plan, including elements of the product.

Learning Objectives

Compare and contrast initial product testing and test marketing

Key Takeaways

Key Points

- Product testing is totally initiated by the producer. He or she selects the sample of people, provides the consumer with the test product, and offers the consumer some sort of incentive to participate.
- In test marketing, the consumer must make the decision him- or herself, must pay using his or her money, and the test product must compete with the existing products in the actual marketing environment.
- Because of the special expertise needed to conduct test markets and the associated expenses, most manufacturers employ independent marketing research agencies with highly trained project directors, statisticians, psychologists, and field supervisors.

Key Terms

- **Market Share**: Percentage of some market held by a company.
- **marketing mix**: The marketing mix is a business tool used in marketing products. The marketing mix is often crucial when determining a product or brand's unique selling point and is often synonymous with the four Ps: price, product, promotion, and place.

Testing is the final step before commercialization. The objective is to test all the variabilites in the marketing plan including elements of the product. Test marketing represents an actual launching of the total marketing program, but on a limited basis.

Three general issues are addressed through test marketing. First, the overall workability of the marketing plan is assessed. Second, alternative allocations of the budget are evaluated. Third, whether the new product is inspiring users to switch from other brands is determined. In the end, the test market should include an estimate of sales, market share, and financial performance over the life of the product.

Product Testing: This is a photo of a temperature and humidity chamber used to simulate transport, warehouse environments, and shelf life conditions of a packaged product.

Initial *product testing* and *test marketing* are not the same. Product testing is totally initiated by the producer. He or she selects a sample of people, provides the consumer with the test product, and offers the consumer some sort of incentive to participate. Test marketing, on the other hand, is distinguished by the fact that the test cities should represent the national market. The consumer must make the decision him- or herself, must pay with his or her money, and the test product must compete with the existing products in the actual marketing environment. For these and other reasons, a market test is an accurate simulation of the national market and serves as a method for reducing risk. It should enhance the new product's probability of success and allow for final adjustment in the marketing mix before the product is introduced on a large scale.

However, running a test marketing simulation has inherent risks. First, there are substantial costs in buying the necessary plant and machinery needed to manufacture the product or locating manufacturers willing to make limited runs. There are also promotional costs, particularly advertising and personal selling. Although not always easy to identify, there are indirect costs as well. For example, the money used to test market could be used for other activities; in other words, there is an opportunity cost. There is also a risk of losing consumer goodwill through the testing of an inferior product. Finally, engaging in a test market might allow competitors to become aware of a new product and quickly copy it.

Because of the special expertise needed to conduct test markets and take on associated expenses, most manufacturers employ independent marketing research agencies with highly trained project directors, statisticians, psychologists, and field supervisors. Such firms assist the product manager in making the remaining test market decisions. These include:

1. Duration of testing: the product should be tested long enough to account for market factors to even out, allow for repeat purchases, and account for deficiencies in any other elements in the new product (three to six months of testing may be sufficient for a frequently purchased and rapidly consumed convenience item).
2. Selection of test market cities: the test market cities should reflect the norms for the new product in such areas as advertising, competition, distribution system, and product usage.
3. Number of test cities: should be based on the number of variations considered (i.e., price, package, or promotion), representativeness, and cost.
4. Sample size determination: the number of stores used should be adequate to represent the total market.

Even after all the test results are in, adjustments in the product are still made. Additional testing may be required, or the product may be discontinued.

Commercialization

Once a product is ready to take to market, commercialization involves key decisions about distribution, promotion, and pricing.

Learning Objectives

Outline the basics of commercialization

Key Takeaways

Key Points

- The actual launch of a new product is the final stage of new product development, and the one where the most money will have to be spent for advertising, sales promotion, and other marketing efforts.

- Commercialization of a product will only take place if the following three questions can be answered: When is the appropriate time to introduce the product? Where is the appropriate market to launch the product? To whom will the product be targeted primarily?
- The company has to decide on an action plan for introducing the product by implementing the above decisions.

Key Terms

- **marketing mix**: The marketing mix is a business tool used in marketing products. The marketing mix is often crucial when determining a product or brand's unique selling point and is often synonymous with the four Ps: price, product, promotion, and place.

Commercialization is the process or cycle of introducing a new product or production method into the market. This actual launch of a new product is the final stage of new product development, and the one where the most money will have to be spent for advertising, sales promotion, and other marketing efforts. Commercialization is often confused with sales, marketing or business development. The commercialization process has three key aspects:

Commercialization: Bringing new products to market will require creative marketing techniques to achieve success like Red Bull did by creating mascot automobiles.

- It is essential to look at many ideas to get one or two products or businesses that can be sustained long-term. This is often known as the funnel.
- Commercialization is a stage-wise process, and each stage has its own key goals and milestones.
- It is vital to involve key stakeholders early on, including customers.

Commercialization of a product will only take place if the following three questions can be answered:

1. *When is the appropriate time to introduce the product?* When facing the danger of cannibalizing the sales of the company's other products, if the product can be improved further, or if the economy is down, the launch should be delayed.
2. *Where is the appropriate market to launch the product?* It can be in a single location, in several regions, or it might be more appropriate for a national or international market. This decision will be strongly influenced by the company's resources in terms of capital, managerial confidence and operational capacities. Smaller companies usually launch in attractive cities or regions, while larger companies enter a national market all at once. Global roll outs are generally only undertaken by multinational conglomerates, since they have the necessary size and make use of international distribution systems. Other multinationals use the "lead-country" strategy by introducing the new product in one country/region at a time.
3. *To whom will the product be targeted primarily?* These primary consumer groups should consist of innovators, early adopters, heavy users and/or opinion leaders. This will ensure adoption by other buyers in the marketplace during the product growth period.

The company has to decide on an action plan for introducing the product by thinking about the questions above and making informed decisions. It has to develop a viable marketing mix and create a respective marketing budget.

Hazz Design: "Brainstorm to Box: Good Design"

Watch this video to learn how design is defined and what makes good design. Good design is often difficult. Once you understand user needs, the creation process requires that those needs be met in the most pleasing and useful way possible. Brainstorming is a

method used to help facilitate good design process.

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TEDxKyoto: Catherine Courage's "Igniting Creativity to Transform Corporate Culture"

Watch this video on the importance of developing a culture of creativity to drive business success. Culture is the foundation of what and how we do things within an organization. The culture must support a creative approach to solving problems, designing product/services, and testing new ideas. Consider how you would apply this information to the operations landscape.

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River Valley TV: Lisa R. Horowitz's "User Needs Research: Generating Ideas for Products and Services"

Watch this lecture on the importance of discovering the needs of your customers/users. A product or service will only be successful if the customer/user finds utility in what you have created. This requires user needs research to help identify areas where you can focus the development of new products/services. Consider how you would gather information on what customers' want/need for your current organization.

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Product Concept Generation

By Mical Nobel

Abstract

Concept generation, getting the ideas, is the most critical step in the engineering design process. Starting with a set of customer needs and target specifications, the process concludes with an array of product alternatives from which a final design is selected. There are multiple steps involved in the generic concept generation process, as well as various approaches. This article reviews and critiques these different perspectives within the context of successfully developing an electronic medical product that is innovative in design and customer appeal.

Introduction

Concept generation, which is when a product development team comes up with the ideas, is the most critical step in the engineering design process – without it, there is no design. A concept can be defined as both an "approximate description of the technology, working principles, and form of the product" as well as a "concise description of how the product will satisfy customer needs" (Ulrich & Eppinger, 2012). Concept generation is a procedure that begins with a set of customer needs and target specifications and results in an array of product concept design alternatives from which a final design will be selected. This step requires a more abstract style of thinking than perhaps most engineers are used to. As Einstein and Infeld (1938) wrote in The Evolution of Physics, the "formulation of a problem is often more essential than its solution, which may be merely a matter of mathematical or experimental skill. To raise new questions, new possibilities, to regard old problems from a new angle, requires creative imagination and marks real advance in science." While many have proposed their own specific theories, approaches, and metrics regarding concept development and, in particular, generation, there are a few general guidelines and postulates that are echoed in each specific method. The common theme: patience and open-mindedness are vital to successful concept generation.

The invention of the light bulb highlights the importance of the concept generation process. Famous inventor Thomas Edison once said, "None of my inventions came by accident. I see a worthwhile need to be met and I make trial after trial until it comes. What it boils down to is 1 percent inspiration and 99 percent perspiration" (Newton, 1989). Edison understood that trying a large quantity of ideas was extremely important, because failure is inevitable. Before finding a stable material for the first successful light bulb, his lab tried and failed with thousands of different filaments (Zenios, et al., 2010). Obviously, the concept that was settled on stuck, because well over 100 years later, commercially available light bulbs are omnipresent.

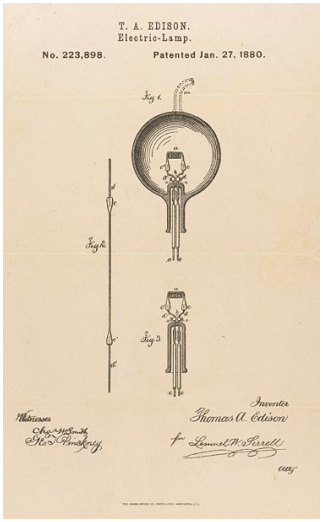

Figure 1 *Thomas Edison's patent drawing and application for an improvement in electric lamps, 1/27/1880; Records of the Patent and Trademark Office; Record Group 241; National Archives [retrieved from the Access to Archival Databases at www.archives.gov, April 24, 2013].*

The Yellow Team, the 2012-2013 Tufts ECE senior design group that served as a case study for this article, faced the added complexities and challenges involved in designing a medical device for their project, which was to digitize an outdated device utilized in assessing glaucoma. Invention is a very intricate process, perhaps more so in the design of medical devices than in most other fields because there are so many factors that must be considered. Some upstream issues include: medical need, gaps in the treatment landscape, stakeholder interests, and market opportunity. Some downstream concerns are: patenting, regulation, reimbursement, and deployment in the healthcare system. Successful concept generation is critical for building a reliable product that will be able to satisfy many multi-faceted requirements.There are two components in the concept generation stage: ideation, and then concept screening. Each component comes with its own set of rules and guidelines. Yet we can combine and break down the whole stage into a generic five step process.

Step One: Clarify and Deconstruct the Problem

Before coming up with any possible solutions, familiarization with some background information may be necessary. Perhaps the most important in a situation where people are looking to develop a solution to needs, the needs specification and problem deconstruction forms the foundation of this background information. For example, the Yellow Team found it important to have an overview of existing treatment options and a basic understanding of electronics and sensors in order to facilitate their flow of ideas and discussion. It is also really critical to decompose a complex problem into simpler sub-problems.

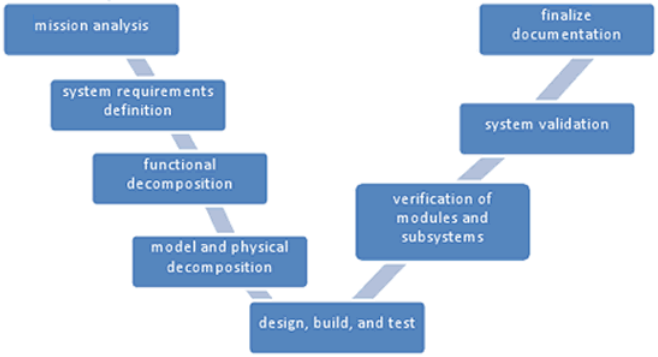

Figure 2 System Engineering Tasks. Source: Lasser (2012).

One can look at a product in development as a system. Many transactions occur relating to this system – what are the inputs being given from the user to the product, and what are the outputs being received? This analysis is important to understand the

dependencies and the risks involved with the product, and help determine what needs to happen in between. The “in-between stuff” are the sub-problems. Systems engineering is a means to enable the realization of successful systems. It focuses on defining customer requirements and necessary functionality before proceeding with design synthesis and system validation while considering the complete problem.

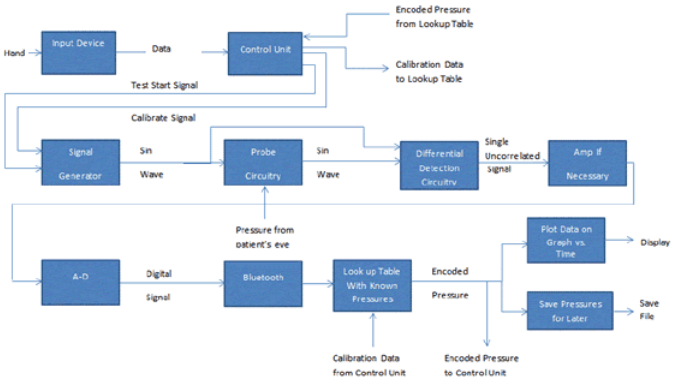

Figure 3 Tufts ECE 2013 Yellow Team’s System Engineering Diagram. Source: Ferrentino at al (2013).

A system engineering diagram can help one look at the big picture, identify the modes of failure, and ultimately optimize the performance of the system. A system engineering diagram increases a system’s probability of success. It helps clarify, for the designer, what the system specifications are. It also helps clarify for the designer which features, functionality, and requirements are unnecessary and can be eliminated. This, in effect, means reduced total development costs and cycle time, as well as overall functional reliability. The Yellow Team’s system engineering diagram (Figure 3) is an example.

Once the problem has been defined and effectively broken down, initial efforts should be focused on critical sub-problems.

Step Two: Search for Solutions

Searching for Solutions Externally

An external search is an information-gathering process. It should be performed to find existing concepts relating to both the overall problem and to the sub-problems identified during the problem clarification step. Implementing an existing solution can be easier, cheaper, and much faster than developing a new solution. Another option is to optimize a pre-existing solution, or to apply it as-is to one sub-problem and pair it with an original concept for another sub-problem, combined to yield a novel and improved overall design.

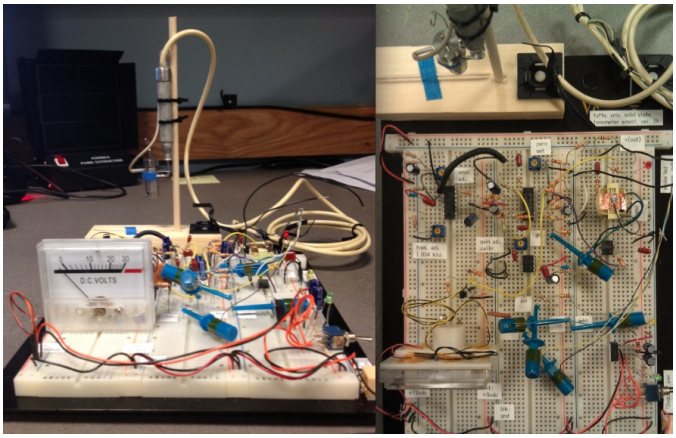

Figure 4 Tufts ECE 2013 Yellow Team’s Reconstructed Tonographer Circuit. Source: Ferrentino et al (2013).

As the Yellow Team learned the hard way, it is much more efficient to proceed with this search by first broadly gathering information that might be related to the problem and then focus the scope of the search by exploring more directed details. An imbalanced approach renders an inefficient external search. Some examples of good resources are the following: searching through patents and published literature – the Yellow Team performed this step throughout the first semester of the project, but found it a somewhat vague resource; benchmark related product – with the help of some department faculty advisors, the Yellow Team was

able to recreate the circuit (Figure 4) of the device in order to fully understand it; interviews with lead users, and consulting experts – the Yellow Team did this by working with an active ophthalmologist to determine the project requirements and finally narrow the scope.

Searching for Solutions Internally

Searching internally for solutions, also known as brainstorming, is an enormous part of successful concept generation. One important thing to keep in mind during this step is to be patient. Engineers love jumping to conclusions, but it's important to be open to the unknown. Successful concept generation requires a new mindset that perfectionism "is the enemy". As a result of contemporary education's emphasis on immediate solutions and fact-finding, today's engineers tend to neglect the consideration of different ideas. Zenios et al. (2010) said that "most of us like to solve problems and move on. Idea finding may seem childlike (and it should be) but at its heart is the exploration of possibilities, free from as many constraints as possible". These opinions are not new. Osborn (1953), the alleged founder of brainstorming, claimed the following four tenets of brainstorming:

- *The judgment of ideas is not allowed*
- Outlandish ideas are encouraged
- A large quantity of ideas is preferred
- Members should build on one another's ideas

IDEO, a contemporary global design consultancy, incorporated Osborn's themes into a proposed set of rules to traditional group brainstorming (IDEO, 2011):

- Defer judgment
- Encourage wild ideas
- Build on the ideas of others
- Stay focused on the topic – minimize noise and don't lose track of the focus for that session
- One conversation at a time
- Be visual – use props, have a scribe, and utilize doodles, diagrams, and buzz words in a logical way that illustrates your ideas
- Go for quantity

Brainstorming describes a set of methods for creative problem solving, implemented in group settings as well as by individuals. The term was popularized by Osborn in his 1953 book, *Applied Imagination*, which launched the study of creativity in business development. The principles Osborn proposed over half a century ago hold just as true today: it is critical that participants – in any variation of a brainstorming session – set aside any preconceived notions or preemptively formed solutions and "temporarily suspend their instinct to criticize new ideas". They must "open their minds to a creative flow" of new possibilities as well as look for original, even unusual, connections among the generated ideas. Critical filtering, while necessary and important at many points throughout product development including later in the concept development process, can be counterproductive to a team's results when first considering solutions. It can be quite difficult for people in science fields, who are so accustomed to producing quick, correct solutions, to restrain from making snap judgments on new ideas. This is one of the many reasons why forming a multidisciplinary team and seeking unique, interdisciplinary perspectives for a group brainstorming session is extremely important.

Concept generation is enormously enabled by including a group of participants with diverse backgrounds, expertise, and perspectives. Establishing a multidisciplinary perspective is particularly paramount in developing medical devices, as opportunities for adapting technologies and approaches from one area to another arise so frequently in the medical technology sector: between physicians and engineers, between different medical specialties, and even between medical and non-medical technologies (Zenios et al., 2010).

Group sessions are critical for building team consensus, communicating information, and refining concepts (Ulrich & Eppinger, 2012). Group sessions can also be useful by allowing any participant to build on the ideas of others. One person's idea can stimulate the creativity of other participants to come up with the next level – a solution enhancement, a novel connection, or just some totally random idea that they would not have thought of otherwise (IDEO, 2011).

Figure 5 Tufts ECE 2013 Yellow Team Meeting and Discussing Ideas with Ophthalmologist. Source: Ferrentino at al (2013).

There are some matters to consider when it comes to picking participants for a brainstorming session, especially when dealing with medical devices. For one, the deeply ingrained value of avoiding damage to patients makes physicians and engineers alike particularly conservative when it comes to pre-screening ideas, along with all their other knowledge and experience based biases. A second important action is to consider all of the areas that potentially will come into play in designing and developing a medical device solution. Find people who understand the field of interest and existing technologies, but also have the ability to see past their own knowledge so as not to bias the group toward a particular type of solution. An alternative approach is to turn this "expert problem" – having someone almost *too* knowledgeable come in with all of their biases and preconceived notions – into an advantage by bringing in an expert to lead some sort of working session can uncork the expert's mind and arouse some interesting ideas. For the Yellow Team, this was the ophthalmologist who acted as both their project sponsor and lead user.

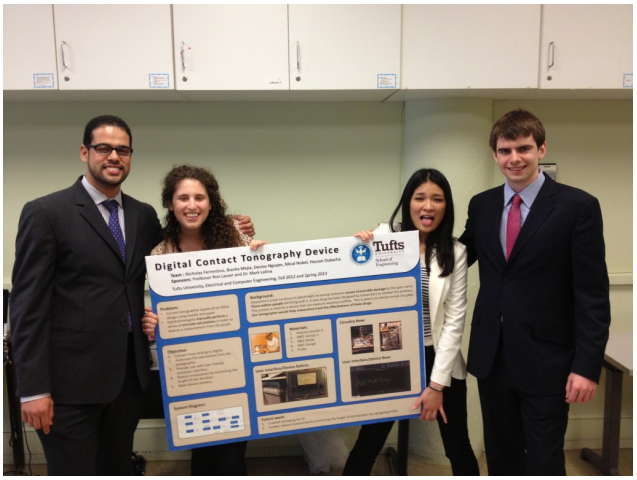

Figure 6 Tufts ECE 2013 Yellow Team's ECE Students at Poster Session. Source: Ferrentino at al (2013).

The Yellow Team and its project exemplify the inevitable interdisciplinary nature of such a product. The project required the efforts of all five team members, from a number of educational backgrounds. The electronics required knowledge of biomedical engineering and electrical, specifically signal processing and processing sensor data. The two electrical engineers and the biomedical engineering double-major on the team were responsible for this section of the project work. Human computer interaction, specifically the user interface is critical to communicating the test results and making the device intuitive for use by trained medical staff. A human factors engineer and a computer engineer worked together to design a graphical user interface that provides functionality for ease of use.

Step Three: Systematically Explore the Solutions

Brainstorming may result in tens or hundreds of ideas that need to be screened, sorted, and then evaluated before any single idea can be chosen. Being selective about which concepts to pursue form the pile generated during the ideation phase is of the utmost

importance. Concept screening involves organizing and analyzing all of the ideas. It is critical to understand how to cluster and organize the output of a brainstorming session so it can be presented and analyzed in a meaningful way. Grouping ideas can reveal potential gaps or biases in the proposed solutions, as well as opportunities to combine ideas into unique, synergistic ones that ultimately yield more optimal, cohesive, and complete solutions that better address the need than any individual concept. It is also crucial to learn how to objectively compare all of the possibilities against the defined need specification to determine which course to pursue based on how well each option satisfies the need.

Effectively organizing data before beginning concept screening primarily boils down to two activities: clustering and concept mapping. The first step to clustering is to identify the primary organizing principle on which the clustering pattern is based. This can be quite challenging, as there are always multiple factors that have significance and benefits in different ways.

Table 1

Organizing Principles prior to concept screening. Source: Von Hippel (page 196, 2004).

Organizing principle	Description
Mechanism of action	Group ideas according to how the solutions are intended to work.
Technical feasibility	Group ideas according to the likelihood of coming to fruition. This is based on understanding what is feasible using current engineering and scientific methods.
Funding required	Group ideas around the amount and/or source of funding required to develop them.
Affected stakeholder	Group ideas around the stakeholder most affected, typically the patient or healthcare provider.

Another approach is to create an organize hierarchy, dividing big clusters into subgroups of smaller clusters based onto additional organizing principles, and so on, incorporating into deeper and deeper levels. After one or more organizing principles have been applied to clusters, the clusters can be documented in a concept map, also known as a mind map. A concept map illustrates how ideas relate to one another and to the main problem or need. These maps help the innovator recognize patterns and build connections. When developing a concept map, the need is placed at the center, with the clusters of ideas spanning in different directions. To be effective, an innovator must strive to ensure that all of the clusters have an obvious relationship to the need.

Screening is intended to filter the vast universe of ideas to the ones that best address the need. This requires rigorous comparison and analysis to the original need statement and the explicitly defined need criteria laid out in the customer specifications to see which concepts satisfy the requirements and which do not. It is essential to not lose focus of these original specifications. Any modification or compromising of the specifications may undermine the integrity of the screening process and lead to poor choices. Concept maps will lead to a greater understanding of the different parameters along which each solution is aligned. While not completely fail-safe, this method is a good attempt at objectively assessing the current state of the concepts. Remember that some solutions may meet the need criteria but still need to be eliminated from consideration because they are too impractical or infeasible given the circumstances, such as technology constraints, potential customer or user concerns, etc. Although relatively rare, if screening yields too many solid potential concepts rather than approaches that meet the need criteria, then the need criteria may be too broad, requiring the innovator to revisit the need specification to generate more specific criteria. Some additional tools that can be used are the concept classification tree, used to reorganize lists or mind maps by function, and the concept combination table, which provides a method for combining solution fragments systematically – each column in the table represents a sub-problem and each row a conceptual solution.

Step Four: Reflect and Refine the Solution

It is important to realize that the ideation and brainstorming steps of the process are not over once they are completed the first time – the concept generation process is cyclical. As new information and new circumstances continue to crop up at all stages of the process, the team may be required to go back into brainstorming mode, for example when refining the direction or approach on an already accepted solution. This process is a feedback loop. Good prototypes tend to provide powerful stimuli for new ideas. The relationship between prototyping and brainstorming is an iterative one.

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