CHAPTER SIX

Concept Generation

Courtesy of The Stanley Works

EXHIBIT 6-1
A cordless electric roofing nailer.

The president of Stanley-Bostitch commissioned a team to develop a new hand-held nailer for the roofing market. The product that eventually resulted from the effort is shown in Exhibit 6-1. The mission of the team was to consider broadly alternative product concepts, assuming only that the tool would employ conventional nails as the basic fastening technology. After identifying a set of customer needs and establishing target product specifications, the team faced the following questions:

- What existing solution concepts, if any, could be successfully adapted for this application?
- What new concepts might satisfy the established needs and specifications?
- What methods can be used to facilitate the concept generation process?

The Activity of Concept Generation

A product concept is an approximate description of the technology, working principles, and form of the product. It is a concise description of how the product will satisfy the customer needs. A concept is usually expressed as a sketch or as a rough three-dimensional model and is often accompanied by a brief textual description. The degree to which a product satisfies customers and can be successfully commercialized depends to a large measure on the quality of the underlying concept. A good concept is sometimes poorly implemented in subsequent development phases, but a poor concept can rarely be manipulated to achieve commercial success. Fortunately, concept generation is relatively inexpensive and can be done relatively quickly in comparison to the rest of the development process. For example, concept generation had typically consumed less than 5 percent of the budget and 15 percent of the development time in previous nailer development efforts. Because the concept generation activity is not costly, there is no excuse for a lack of diligence and care in executing a sound concept generation method.

The concept generation process begins with a set of customer needs and target specifications and results in a set of product concepts from which the team will make a final selection. The relation of concept generation to the other concept development activities is shown in Exhibit 6-2. In most cases, an effective development team will generate hundreds of concepts, of which 5 to 20 will merit serious consideration during the concept selection activity.

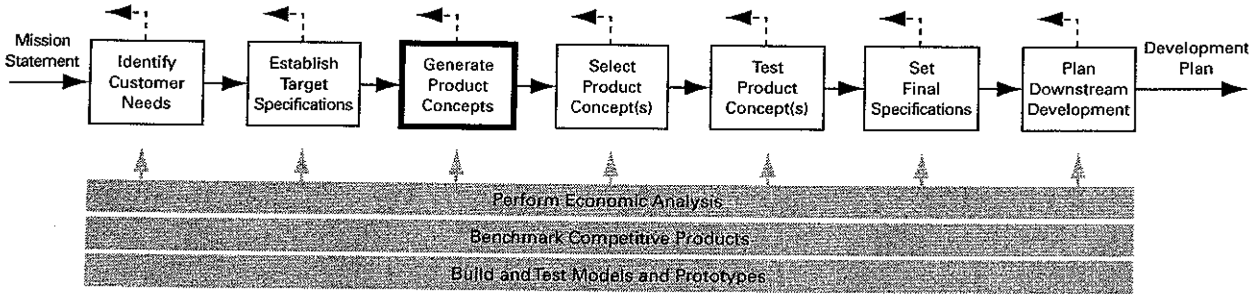


EXHIBIT 6-2 Concept generation is an integral part of the concept development phase.

Good concept generation leaves the team with confidence that the full space of alternatives has been explored. Thorough exploration of alternatives early in the development process greatly reduces the likelihood that the team will stumble upon a superior concept late in the development process or that a competitor will introduce a product with dramatically better performance than the product under development.

Structured Approaches Reduce the Likelihood of Costly Problems

Common dysfunctions exhibited by development teams during concept generation include:

- Consideration of only one or two alternatives, often proposed by the most assertive members of the team.
- Failure to consider carefully the usefulness of concepts employed by other firms in related and unrelated products.
- Involvement of only one or two people in the process, resulting in lack of confidence and commitment by the rest of the team.
- Ineffective integration of promising partial solutions.
- Failure to consider entire categories of solutions.

A structured approach to concept generation reduces the incidence of these problems by encouraging the gathering of information from many disparate information sources, by guiding the team in the thorough exploration of alternatives, and by providing a mechanism for integrating partial solutions. A structured method also provides a step-by-step procedure for those members of the team who may be less experienced in design-intensive activities, allowing them to participate actively in the process.

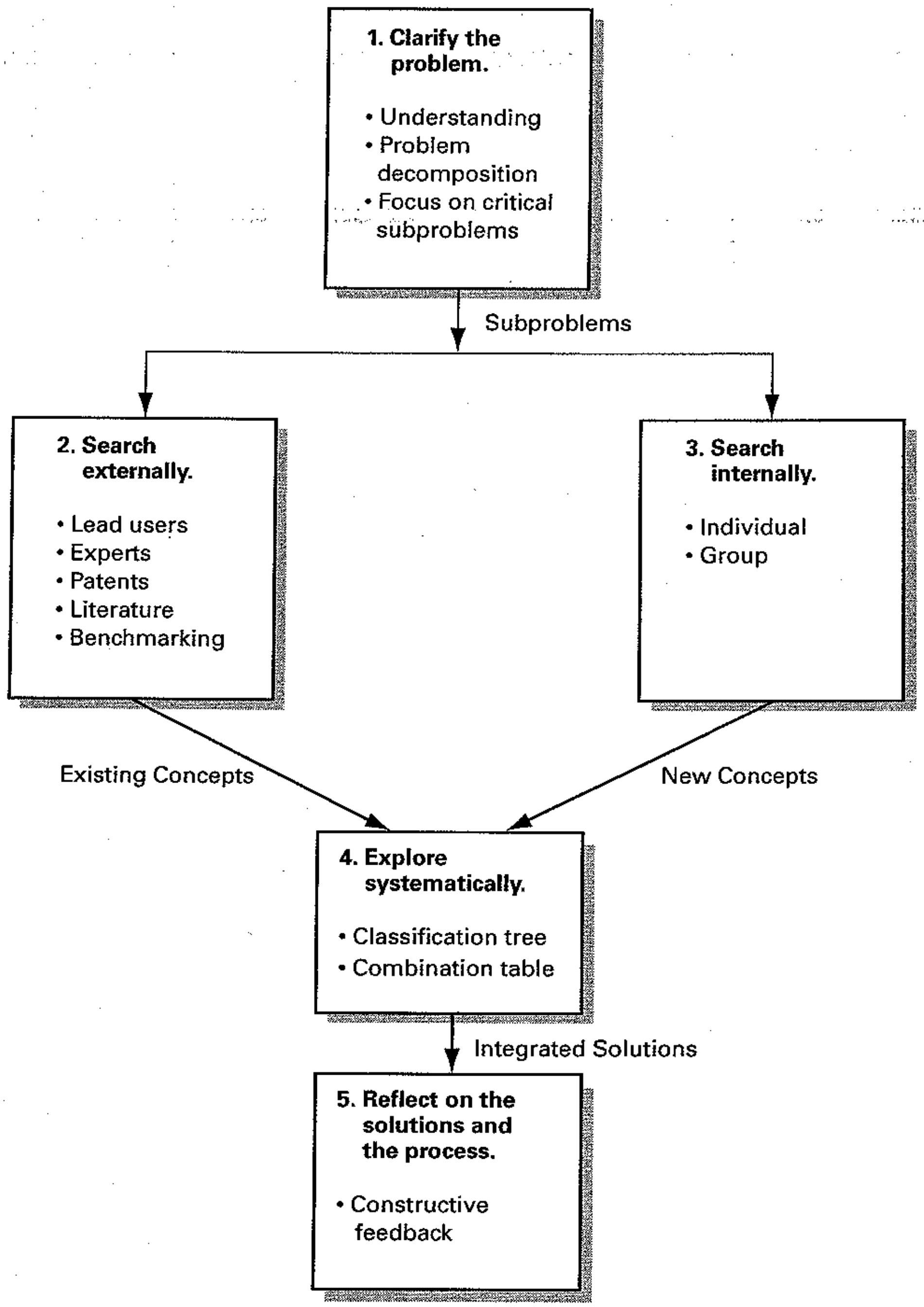
A Five-Step Method

This chapter presents a five-step concept generation method. The method, outlined in Exhibit 6-3, breaks a complex problem into simpler subproblems. Solution concepts are then identified for the subproblems by external and internal search procedures. Classification trees and concept combination tables are then used to systematically explore the space of solution concepts and to integrate the subproblem solutions into a total solution. Finally, the team takes a step back to reflect on the validity and applicability of the results, as well as on the process used.

This chapter will follow the recommended method and will describe each of the five steps in detail. Although we present the method in a linear sequence, concept generation is almost always iterative. Like our other development methods, these steps are intended to be a baseline from which product development teams can develop and refine their own unique problem-solving style.

Our presentation of the method is focused primarily on the overall concept for a new product; however, the method can and should be used at several different points in the development process. The process is useful not only for overall product concepts but also for concepts for subsystems and specific components as well. Also note that while the example in this chapter involves a relatively technical product, the same basic approach can be applied to nearly any product.

EXHIBIT 6-3
The five-step concept generation method.



Step 1: Clarify the Problem

Clarifying the problem consists of developing a general understanding and then breaking the problem down into subproblems if necessary.

The mission statement for the project, the customer needs list, and the preliminary product specification are the ideal inputs to the concept generation process, although often these pieces of information are still being refined as the concept generation phase begins. Ideally the team has been involved both in the identification of the customer needs and in the setting of the target product specifications. Those members of the team who were not involved in these preceding steps should become familiar with the processes used and their results before concept generation activities begin. (See Chapter 4, Identifying Customer Needs, and Chapter 5, Product Specifications.)

As stated before, the challenge was to "design a better hand-held roofing nailer." The scope of the design problem could have been defined more generally (e.g., "fasten roofing materials") or more specifically (e.g., "improve the speed of the existing pneumatic tool concept"). Some of the assumptions in the team's mission statement were:

- The nailer will use nails (as opposed to adhesives, screws, etc.).
- The nailer will be compatible with nail magazines on existing tools.
- The nailer will nail through roofing shingles into wood.
- The nailer will be hand-held.

Based on the assumptions, the team had identified the customer needs for a hand-held nailer. These included:

- The nailer inserts nails in rapid succession.
- The nailer is lightweight.
- The nailer has no noticeable nailing delay after tripping the tool.

The team gathered supplemental information to clarify and quantify the needs, such as the approximate energy and speed of the nailing. These basic needs were subsequently translated into target product specifications. The target specifications included the following:

- Nail lengths from 25 millimeters to 38 millimeters.
- Maximum nailing energy of 40 joules per nail.
- Nailing forces of up to 2,000 newtons.
- Peak nailing rate of one nail per second.
- Average nailing rate of 12 nails per minute.
- Tool mass less than 4 kilograms.
- Maximum trigger delay of 0.25 second.

Decompose a Complex Problem into Simpler Subproblems

Many design challenges are too complex to solve as a single problem and can be usefully divided into several simpler subproblems. For example, the design of a complex product like a document copier can be thought of as a collection of more focused design problems, including, for example, the design of a document handler, the design of a paper feeder, the design of a printing device, and the design of an image capture device. In some cases, however, the design problem cannot readily be divided into subproblems. For example, the problem of designing a paper clip may be hard to divide into subproblems. As a general rule, we feel that teams should attempt to decompose design problems, but should be aware that such a decomposition may not be very useful for products with extremely simple functions.

Dividing a problem into simpler subproblems is called *problem decomposition.* There are many schemes by which a problem can be decomposed. Here we demonstrate a *functional* decomposition and also list several other approaches that are frequently useful.

solutions. This approach involves a conscious decision to defer the solution of some of the subproblems. For example, the nailer team chose to focus on the subproblems of storing/accepting energy, converting the energy to translational energy, and applying the translational energy to the nail. The team felt confident that the nail handling and triggering issues could be solved after the energy storage and conversion issues were addressed. The team also deferred most of the user interaction issues of the tool. The team believed that the choice of a basic working principle for the tool would so constrain the eventual form of the tool that they had to begin with the core technology and then proceed to consider how to embody that technology in an attractive and user-friendly form. Teams can usually agree after a few minutes of discussion on which subproblems should be addressed first and which should be deferred for later consideration.

Step 2: Search Externally

External search is aimed at finding existing solutions to both the overall problem and the subproblems identified during the problem clarification step. While external search is listed as the second step in the concept generation method, this sequential labeling is deceptive; external search occurs continually throughout the development process. Implementing an existing solution is usually quicker and cheaper than developing a new solution. Liberal use of existing solutions allows the team to focus its creative energy on the critical subproblems for which there are no satisfactory prior solutions. Furthermore, a conventional solution to one subproblem can frequently be combined with a novel solution to another subproblem to yield a superior overall design. For this reason external search includes detailed evaluation not only of directly competitive products but also of technologies used in products with related subfunctions.

The external search for solutions is essentially an information-gathering process. Available time and resources can be optimized by using an expand-and-focus strategy: first *expand* the scope of the search by broadly gathering information that might be related to the problem and then *focus* the scope of the search by exploring the promising directions in more detail. Too much of either approach will make the external search inefficient.

There are at least five good ways to gather information from external sources: lead user interviews, expert consultation, patent searches, literature searches, and competitive benchmarking.

Interview Lead Users

While identifying customer needs, the team may have sought out or encountered lead users. *Lead users* are those users of a product who experience needs months or years before the majority of the market and stand to benefit substantially from a product innovation (von Hippel, 1988). Frequently these lead users will have already invented solutions to meet their needs. This is particularly true among highly technical user communities, such as those in the medical or scientific fields. Lead users may be sought out in the market for which the team is developing the new product, or they may be found in markets for products implementing some of the subfunctions of the product.

In the hand-held nailer case, the nailer team consulted with the building contractors from the PBS television series *This Old House* in order to solicit new concepts. These lead users, who are exposed to tools from many manufacturers, made many interesting observations about the weaknesses in existing tools, but in this case did not provide many new product concepts.

Consult Experts

Experts with knowledge of one or more of the subproblems not only can provide solution concepts directly but also can redirect the search in a more fruitful area. Experts may include professionals at firms manufacturing related products, professional consultants, university faculty, and technical representatives of suppliers. These people can be found by calling universities, by calling companies, and by looking up authors of articles. While finding experts can be hard work, it is almost always less time consuming than re-creating existing knowledge.

Most experts are willing to talk on the telephone or meet in person for an hour or so without charge. In general, consultants will expect to be paid for time they spend on a problem beyond an initial meeting or telephone conversation. Suppliers are usually willing to provide several days of effort without direct compensation if they anticipate that someone will use their product as a component in a design. Of course, experts at directly competing firms are in most cases unwilling to provide proprietary information about their product designs. A good habit to develop is to always ask people consulted to suggest others who should be contacted. The best information often comes from pursuing these "second generation" leads.

The nailer design team consulted dozens of experts, including a rocket fuel specialist, electric motor researchers at MIT, and engineers from a vendor of gas springs. Most of this consultation was done on the telephone, although the engineers from the spring vendor made two trips to visit the team, at their company's expense.

Search Patents

Patents are a rich and readily available source of technical information containing detailed drawings and explanations of how many products work. The main disadvantage of patent searches is that concepts found in recent patents are protected (generally for 20 years from the date of the patent application), so there may be a royalty involved in using them. However, patents are also useful to see what concepts are already protected and must be avoided or licensed. Concepts contained in foreign patents without global coverage and in expired patents can be used without payment of royalties.

The formal indexing scheme for patents is difficult for novices to navigate. Fortunately, several databases contain the actual text of all patents. These text databases can be searched electronically by key words. Key word searches can be conducted efficiently with only modest practice and are remarkably effective in finding patents relevant to a particular product. Copies of U.S. patents including illustrations can be obtained for a nominal fee from the U.S. Patent and Trademark Office and from several suppliers. (See the web site www.ulrich-eppinger.net for a current list of online patent databases and suppliers of patent documents.)

A U.S. patent search in the area of nailers revealed several interesting concepts. One of the patents described a motor-driven double-flywheel nailer. One of the illustrations from this patent is shown in Exhibit 6-5. The design in this patent uses the accumulation of rotational kinetic energy in a flywheel, which is then suddenly converted into translational energy by a friction clutch. The energy is then delivered to the nail with a single impact of a drive pin.

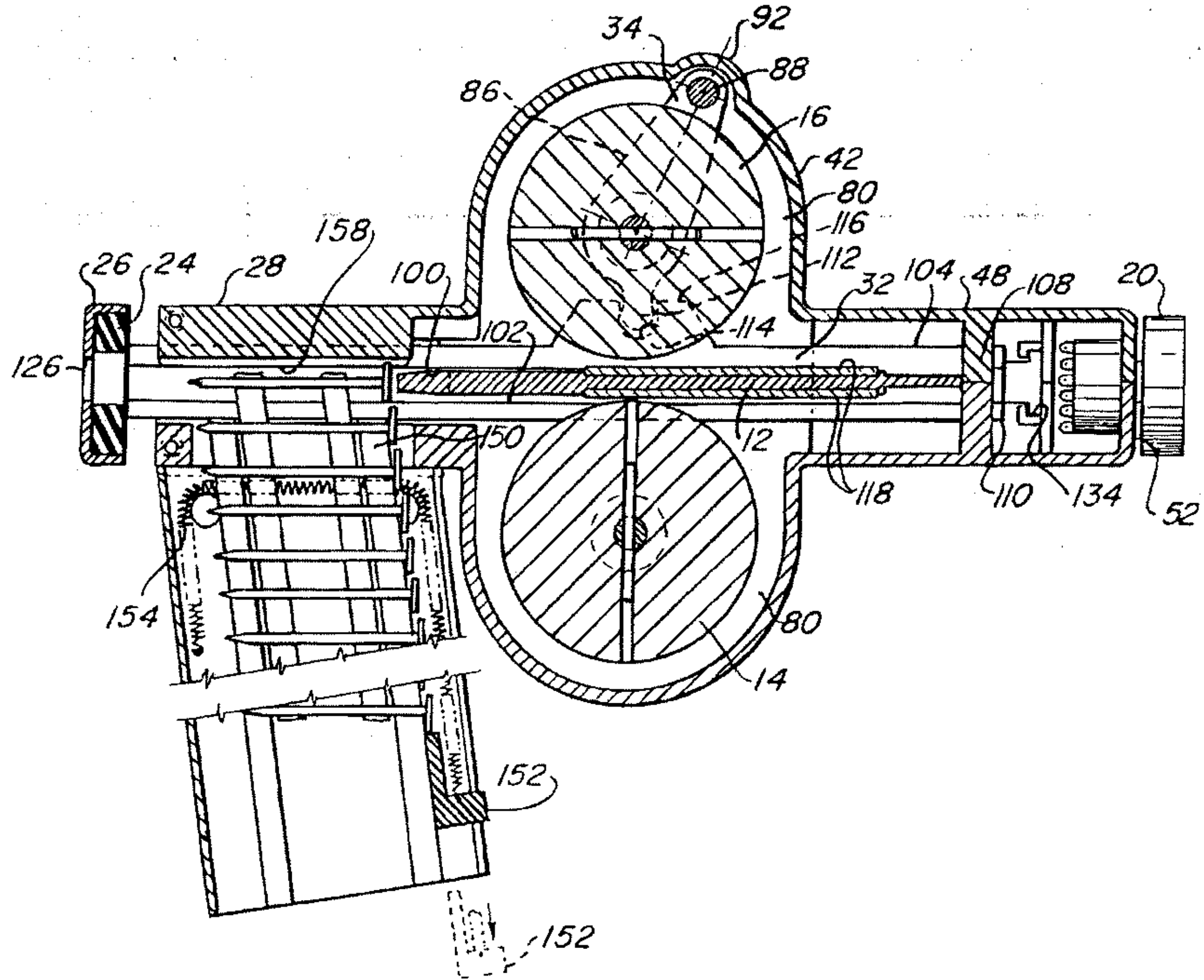


EXHIBIT 6-5 Concept from motor-driven double-flywheel nailer patent (U.S. Patent 4,042,036). The accompanying text describing the patent is nine pages long.

Search Published Literature

Published literature includes journals; conference proceedings; trade magazines; government reports; market, consumer, and product information; and new product announcements. Literature searches are therefore very fertile sources of existing solutions.

Electronic searches are frequently the most efficient way to gather information from published literature. Searching the Internet is often a good first step, although the quality of the results can be hard to assess. More structured databases are available from online sources. Many databases store only abstracts of articles and not the full text and diagrams. A follow-up search for an actual article is often needed for complete information. The two main difficulties in conducting good database searches are determining the key words and limiting the scope of the search. There is a trade-off between the need to use more key words for complete coverage and the need to restrict the number of matches to a manageable number.

Handbooks cataloging technical information can also be very useful references for external search. Examples of such engineering references are *Marks' Standard Handbook of Mechanical Engineering, Perry's Chemical Engineers' Handbook,* and *Mechanisms and Mechanical Devices Sourcebook.*

The nailer team found several useful articles related to the subproblems, including articles on energy storage describing flywheel and battery technologies. In a handbook they found an impact tool mechanism that provided a useful energy conversion concept.

Benchmark Related Products

In the context of concept generation, *benchmarking* is the study of existing products with functionality similar to that of the product under development or to the subproblems on which the team is focused. Benchmarking can reveal existing concepts that have been implemented to solve a particular problem, as well as information on the strengths and weaknesses of the competition.

At this point the team will likely already be familiar with the competitive and closely related products. Products in other markets, but with related functionality, are more difficult to find. One of the most useful sources of this information is the *Thomas Register of American Manufacturers,* a directory of manufacturers of industrial products organized by product type. Often the hardest part of using the *Thomas Register* is finding out what related products are actually called and how they are cataloged. The *Thomas Register* can be accessed via the Internet.

For the nailer, the closely related products included a single-shot gunpowder-actuated tool for nailing into concrete, an electrical solenoid-actuated tacker, a pneumatic nailer for factory use, and a palm-held multiblow pneumatic nailer. The products with related functionality (in this case, energy storage and conversion) included air bags and the sodium azide propellant used as an energy source, chemical hand warmers for skiing, air rifles powered by carbon dioxide cartridges, and portable computers and their battery packs. The team obtained and disassembled most of these related products in order to discover the general concepts on which they were based, as well as other, more detailed information, including, for example, the names of the suppliers of specific components.

External search is an important method of gathering solution concepts. Skill in conducting external searches is therefore a valuable personal and organizational asset. This ability can be developed through careful observation of the world in order to develop a mental database of technologies and through the development of a network of professional contacts. Even with the aid of personal knowledge and contacts, external search remains "detective work" and is completed most effectively by those who are persistent and resourceful in pursuing leads and opportunities.

Step 3: Search Internally

Internal search is the use of personal and team knowledge and creativity to generate solution concepts. The search is *internal* in that all of the ideas to emerge from this step are created from knowledge already in the possession of the team. This activity may be the most open-ended and creative of any in new-product development. We find it useful to think of internal search as a process of retrieving a potentially useful piece of information from one's memory and then adapting that information to the problem at hand. This process can be carried out by individuals working in isolation or by a group of people working together.

Four guidelines are useful for improving both individual and group internal search:

1. ***Suspend judgment.*** In most aspects of daily life, success depends on an ability to quickly evaluate a set of alternatives and take action. For example, none of us would be very productive if deciding what to wear in the morning or what to eat for breakfast involved an extensive period of generating alternatives before making a judgment. Because most decisions in our day-to-day lives have implications of only a few minutes or hours, we are accustomed to making decisions quickly and moving on. Concept generation for product development is fundamentally different. We have to live with the consequences of product concept decisions for years. As a result, suspending evaluation for the days or weeks required to generate a large set of alternatives is critical to success. The imperative to suspend judgment is frequently translated into the rule that during group concept generation sessions no criticism of concepts is allowed. A better approach is for individuals perceiving weaknesses in concepts to channel any judgmental tendencies into suggestions for improvements or alternative concepts.

2. ***Generate a lot of ideas.*** Most experts believe that the more ideas a team generates, the more likely the team is to explore fully the solution space. Striving for quantity lowers the expectations of quality for any particular idea and therefore may encourage people to share ideas they may otherwise view as not worth mentioning. Further, each idea acts as a stimulus for other ideas, so a large number of ideas has the potential to stimulate even more ideas.

3. ***Welcome ideas that may seem infeasible.*** Ideas which initially appear infeasible can often be improved, "debugged," or "repaired" by other members of the team. The more infeasible an idea, the more it stretches the boundaries of the solution space and encourages the team to think of the limits of possibility. Therefore, infeasible ideas are quite valuable and their expression should be encouraged.

4. ***Use graphical and physical media.*** Reasoning about physical and geometric information with words is difficult. Text and verbal language are inherently inefficient vehicles for describing physical entities. Whether working as a group or as an individual, abundant sketching surfaces should be available. Foam, clay, cardboard, and other three-dimensional media may also be appropriate aids for problems requiring a deep understanding of form and spatial relationships.

Both Individual and Group Sessions Can Be Useful

Formal studies of group and individual problem solving suggest that a set of people working alone for a period of time will generate more and better concepts than the same people working together for the same time period (McGrath, 1984). This finding is contrary to the actual practices of the many firms that perform most of their concept generation activities in group sessions. Our observations confirm the formal studies, and we believe that team members should spend at least some of their concept generation time working alone. We also believe that group sessions are critical for building consensus, communicating information, and refining concepts. In an ideal setting, each individual on the team would spend several hours working alone and then the group would get together to discuss and improve the concepts generated by individuals.

However, we also know that there is a practical reason for holding group concept generation sessions: it is one way to guarantee that the individuals in the group will devote a certain amount of time to the task. Especially in very intense and demanding work environments, without scheduling a meeting, few people will allocate several hours for concentrated individual effort on generating new concepts. The phone rings, people interrupt, urgent problems demand attention. In certain environments, scheduled group sessions may be the only way to guarantee that enough attention is paid to the concept generation activity.

The nailer team used both individual effort and group sessions for internal search. For example, during one particular week each member was assigned one or two subproblems and was expected to develop at least 10 solution concepts. This divided the concept generation work among all members. The group then met to discuss and expand on the individually generated concepts. The more promising concepts were investigated further.

Hints for Generating Solution Concepts

Experienced individuals and teams can usually just sit down and begin generating good concepts for a subproblem. Often these people have developed a set of techniques they use to stimulate their thinking, and these techniques have become a natural part of their problem-solving process. Novice product development professionals may be aided by a set of hints that stimulate new ideas or encourage relationships among ideas. VanGundy (1988), von Oech (1998), and McKim (1980) give dozens of helpful suggestions. Here are some hints we have found to be helpful:

- ***Make analogies.*** Experienced designers always ask themselves what other devices solve a related problem. Frequently they will ask themselves if there is a natural or biological analogy to the problem. They will think about whether their problem exists at a much larger or smaller dimensional scale than that which they are considering. They will ask what devices do something similar in an unrelated area of application. The nailer team, when posing these questions, realized that construction pile drivers are similar to nailers in some respects. In following up on this idea, they developed the concept of a multiblow tool.
- ***Wish and wonder.*** Beginning a thought or comment with "I wish we could . . ." or "I wonder what would happen if . . ." helps to stimulate oneself or the group to consider new possibilities. These questions cause reflection on the boundaries of the problem. For example, a member of the nailer team, when confronted with the required length of a rail gun (an electromagnetic device for accelerating a projectile) for driving a nail, said, "I wish the tool could be 1 meter long." Discussion of this comment led to the idea that perhaps a long tool could be used like a cane for nailing decking, allowing users to remain on their feet.
- ***Use related stimuli.*** Most individuals can think of a new idea when presented with a new stimulus. Related stimuli are those stimuli generated in the context of the problem at hand. For example, one way to use related stimuli is for each individual in a group session to generate a list of ideas (working alone) and then pass the list to his or her neighbor. Upon reflection on someone else's ideas, most people are able to generate new ideas. Other related stimuli include customer needs statements and photographs of the use environment of the product.

- ***Use unrelated stimuli.*** Occasionally, random or unrelated stimuli can be effective in encouraging new ideas. An example of such a technique is to choose, at random, one of a collection of photographs of objects, and then to think of some way that the randomly generated object might relate to the problem at hand. In a variant of this idea, individuals can be sent out on the streets with a digital camera to capture random images for subsequent use in stimulating new ideas. (This may also serve as a good change of pace for a tired group.)
- ***Set quantitative goals.*** Generating new ideas can be exhausting. Near the end of a session, individuals and groups may find quantitative goals useful as a motivating force. The nailer team frequently issued individual concept generation assignments with quantitative targets of 10 to 20 concepts.
- ***Use the gallery method.*** The *gallery method* is a way to display a large number of concepts simultaneously for discussion. Sketches, usually one concept to a sheet, are taped or pinned to the walls of the meeting room. Team members circulate and look at each concept. The creator of the concept may offer explanation, and the group subsequently makes suggestions for improving the concept or spontaneously generates related concepts. This method is a good way to merge individual and group efforts.

In the 1990s, a Russian problem-solving methodology called TRIZ (a Russian acronym for *theory of inventive problem solving*) began to be disseminated in Europe and in the United States. The methodology is primarily useful in identifying physical working principles to solve technical problems. The key idea underlying TRIZ is to identify a contradiction that is implicit in a problem. For example, a contradiction in the nailer problem might be that increasing power (a desirable characteristic) would also tend to increase weight (an undesirable characteristic). One of the TRIZ tools is a matrix of 39 by 39 characteristics with each cell corresponding to a particular conflict between two characteristics. In each cell of the matrix, up to four physical principles are suggested as ways of resolving the corresponding conflict. There are 40 basic principles, including, for example, the *periodic action* principle (i.e., replace a continuous action with a periodic action, like an impulse). Using TRIZ, the nailer team might have arrived at the concept of using repeated smaller impacts to drive the nail. The idea of identifying a conflict in the design problem and then thinking about ways to resolve the conflict appears to be a very useful problem-solving heuristic. This approach can be useful in generating concepts even without adopting the entire TRIZ methodology.

Exhibit 6-6 shows some of the solutions the nailer team generated for the subproblems of (1) storing or accepting energy and (2) delivering translational energy to a nail.

Step 4: Explore Systematically

As a result of the external and internal search activities, the team will have collected tens or hundreds of concept *fragments*—solutions to the subproblems. Systematic exploration is aimed at navigating the space of possibilities by organizing and synthesizing these solution fragments. The nailer team focused on the energy storage, conversion, and delivery subproblems and had generated dozens of concept fragments for each subproblem. One approach to organizing and synthesizing these fragments would be to consider all of the

EXHIBIT 6-6
Some of the solutions to the subproblems of (1) storing or accepting energy and (2) delivering translational energy to a nail.

Solutions to Subproblem of Storing or Accepting Energy

- Self-regulating chemical reaction emitting high-pressure gas
- Carbide (as for lanterns)
- Combusting sawdust from job site
- Gun powder
- Sodium azide (air bag explosive)
- Fuel-air combustion (butane, propane, acetylene, etc.)
- Compressed air (in tank or from compressor)
- Carbon dioxide in tank
- Electric wall outlet and cord
- High-pressure oil line (hydraulics)
- Flywheel with charging (spin-up)
- Battery pack on tool, belt, or floor
- Fuel cell
- Human power: arms or legs
- Methane from decomposing organic materials
- "Burning" like that of chemical hand warmers
- Nuclear reactions
- Cold fusion
- Solar electric cells
- Solar-steam conversion
- Steam supply line
- Wind
- Geothermal

Solutions to Subproblem of Applying Translational Energy to Nail

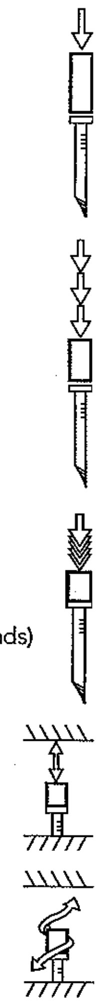
Single impact

Multiple impacts (tens or hundreds)

Multiple impacts (hundreds or thousands)

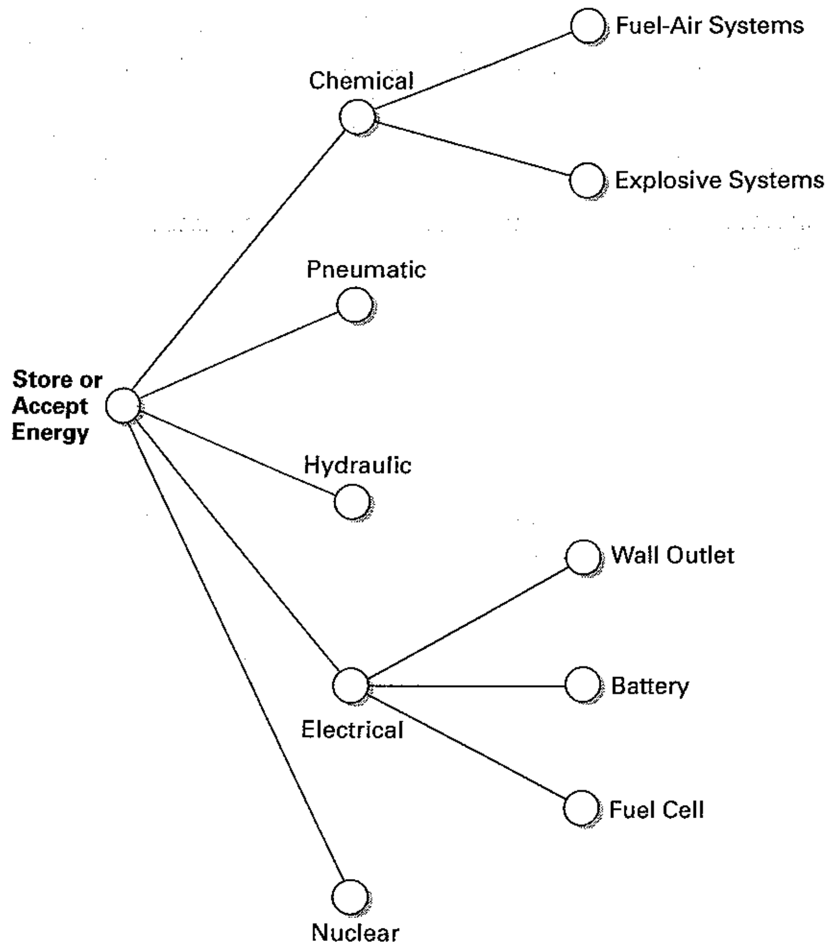
Push

Twist-push



possible combinations of the fragments associated with each subproblem; however, a little arithmetic reveals the impossibility of this approach. Given the three subproblems on which the team focused and an average of 15 fragments for each subproblem, the team would have to consider 3,375 combinations of fragments ($15 \times 15 \times 15$). This would be a daunting task for even the most enthusiastic team. Furthermore, the team would quickly discover that many of the combinations do not even make sense. Fortunately, there are two specific tools for managing this complexity and organizing the thinking of the team: the *concept classification tree* and the *concept combination table.* The classification tree helps the team divide the possible solutions into independent categories. The combination table guides the team in selectively considering combinations of fragments.

EXHIBIT 6-7
A classification tree for the nailer energy source concept fragments.



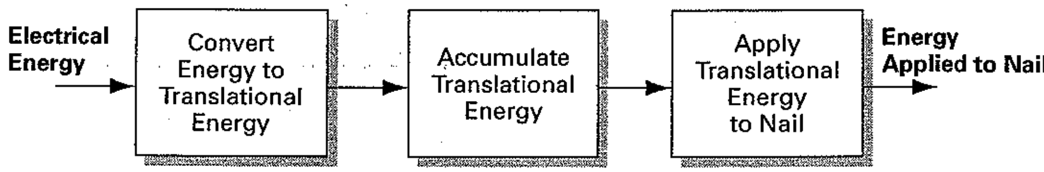
Concept Classification Tree

The concept classification tree is used to divide the entire space of possible solutions into several distinct classes which will facilitate comparison and pruning. An example of a tree for the nailer example is shown in Exhibit 6-7. The branches of this tree correspond to different energy sources.

The classification tree provides at least four important benefits:

1. ***Pruning of less promising branches:*** If by studying the classification tree the team is able to identify a solution approach that does not appear to have much merit, then this approach can be pruned and the team can focus its attention on the more promising branches of the tree. Pruning a branch of the tree requires some evaluation and judgment and should therefore be done carefully, but the reality of product development is that there are limited resources and that focusing the available resources on the most promising directions is an important success factor. For the nailer team, the nuclear energy source was pruned from consideration. Although the team had identified some very intriguing nuclear devices for use in powering artificial hearts, they felt that these devices would not be economically practical for at least a decade and would probably be hampered by regulatory requirements indefinitely.

EXHIBIT 6-8
A new problem decomposition assuming an electrical energy source and the accumulation of energy in the mechanical domain.



2. ***Identification of independent approaches to the problem:*** Each branch of the tree can be considered a different approach to solving the overall problem. Some of these approaches may be almost completely independent of each other. In these cases, the team can cleanly divide its efforts among two or more individuals or task forces. When two approaches both look promising, this division of effort can reduce the complexity of the concept generation activities. It also may engender some healthy competition among the approaches under consideration. The nailer team found that both the chemical/explosive branch and the electrical branch appeared quite promising. They assigned these two approaches to two different subteams and pursued them independently for several weeks.

3. ***Exposure of inappropriate emphasis on certain branches:*** Once the tree is constructed, the team is able to reflect quickly on whether the effort applied to each branch has been appropriately allocated. The nailer team recognized that they had applied very little effort to thinking about hydraulic energy sources and conversion technologies. This recognition guided them to focus on this branch of the tree for a few days.

4. ***Refinement of the problem decomposition for a particular branch:*** Sometimes a problem decomposition can be usefully tailored to a particular approach to the problem. Consider the branch of the tree corresponding to the electrical energy source. Based on additional investigation of the nailing process, the team determined that the instantaneous power delivered during the nailing process was about 10,000 watts for a few milliseconds and so exceeds the power which is available from a wall outlet, a battery, or a fuel cell (of reasonable size, cost, and mass). They concluded, therefore, that energy must be accumulated over a substantial period of the nailing cycle (say 100 milliseconds) and then suddenly released to supply the required instantaneous power to drive the nail. This quick analysis led the team to add a subfunction ("accumulate translational energy") to their function diagram (see Exhibit 6-8). They chose to add the subfunction after the conversion of electrical energy to mechanical energy, but briefly considered the possibility of accumulating the energy in the electrical domain with a capacitor. This kind of refinement of the function diagram is quite common as the team makes more assumptions about the approach and as more information is gathered.

The classification tree in Exhibit 6-7 shows the alternative solutions to the energy source subproblem. However, there are other possible trees. The team might have chosen to use a tree classifying the alternative solutions to the energy delivery subproblem, showing branches for single impact, multiple impact, or pushing. Trees can be constructed with branches corresponding to the solution fragments of any of the subproblems, but certain classifications are more useful. In general, a subproblem whose solution highly constrains the possible solutions to the remaining subproblems is a good candidate for a classification tree. For example, the choice of energy source (electrical, nuclear, pneumatic, etc.) constrains whether a motor or a piston-cylinder can be used to convert the energy to translational energy. In contrast, the choice of energy delivery mechanism (single impact,

Convert Electrical Energy to Translational Energy	Accumulate Energy	Apply Translational Energy to Nail
Rotary motor with transmission	Spring	Single impact
Linear motor	Moving mass	Multiple impacts
Solenoid		Push nail
Rail gun		

EXHIBIT 6-9 Concept combination table for the hand-held nailer.

multiple impact, etc.) does not greatly constrain the solutions to the other subproblems. Reflection on which subproblem is likely to most highly constrain the solutions to the remaining subproblems will usually lead to one or two clear ways to construct the classification tree.

Concept Combination Table

The concept combination table provides a way to consider combinations of solution fragments systematically. Exhibit 6-9 shows an example of a combination table that the nailer team used to consider the combinations of fragments for the electrical branch of the classification tree. The columns in the table correspond to the subproblems identified in Exhibit 6-8. The entries in each column correspond to the solution fragments for each of these subproblems derived from external and internal search. For example, the subproblem of converting electrical energy to translational energy is the heading for the first column. The entries in this column are a rotary motor with a transmission, a linear motor, a solenoid, and a rail gun.

Potential solutions to the overall problem are formed by combining one fragment from each column. For the nailer example, there are 24 possible combinations ($4 \times 2 \times 3$). Choosing a combination of fragments does not lead spontaneously to a solution to the overall problem. The combination of fragments must usually be developed and refined before an integrated solution emerges. This development may not even be possible or may lead to more than one solution, but at a minimum it involves additional creative thought. In some ways, the combination table is simply a way to make forced associations among fragments in order to stimulate further creative thinking; in no way does the mere act of selecting a combination yield a complete solution.

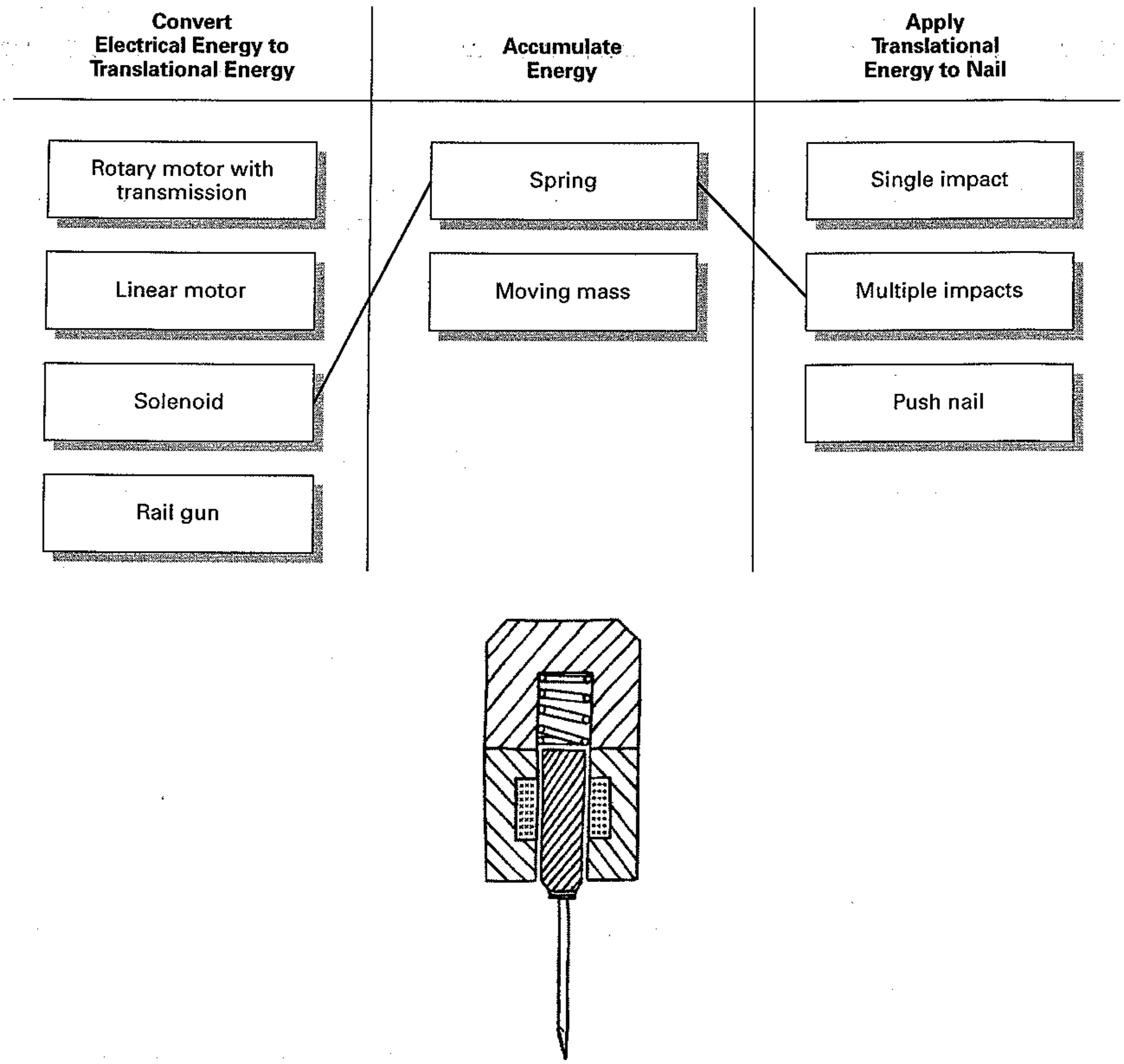


EXHIBIT 6-10 In this solution concept, a solenoid compresses a spring and then releases it repeatedly in order to drive the nail with multiple impacts.

Exhibit 6-10 shows a sketch of a concept arising from the combination of the fragments "solenoid," "spring," and "multiple impacts." Exhibit 6-11 shows some sketches of concepts arising from the combination of the fragments "rotary motor with transmission," "spring," and "single impact." Exhibit 6-12 shows a sketch of a concept arising from the combination of "rotary motor with transmission," "spring," and "multiple impacts." Exhibit 6-13 shows some sketches of concepts arising from the combination of "linear motor," "moving mass," "and single impact."

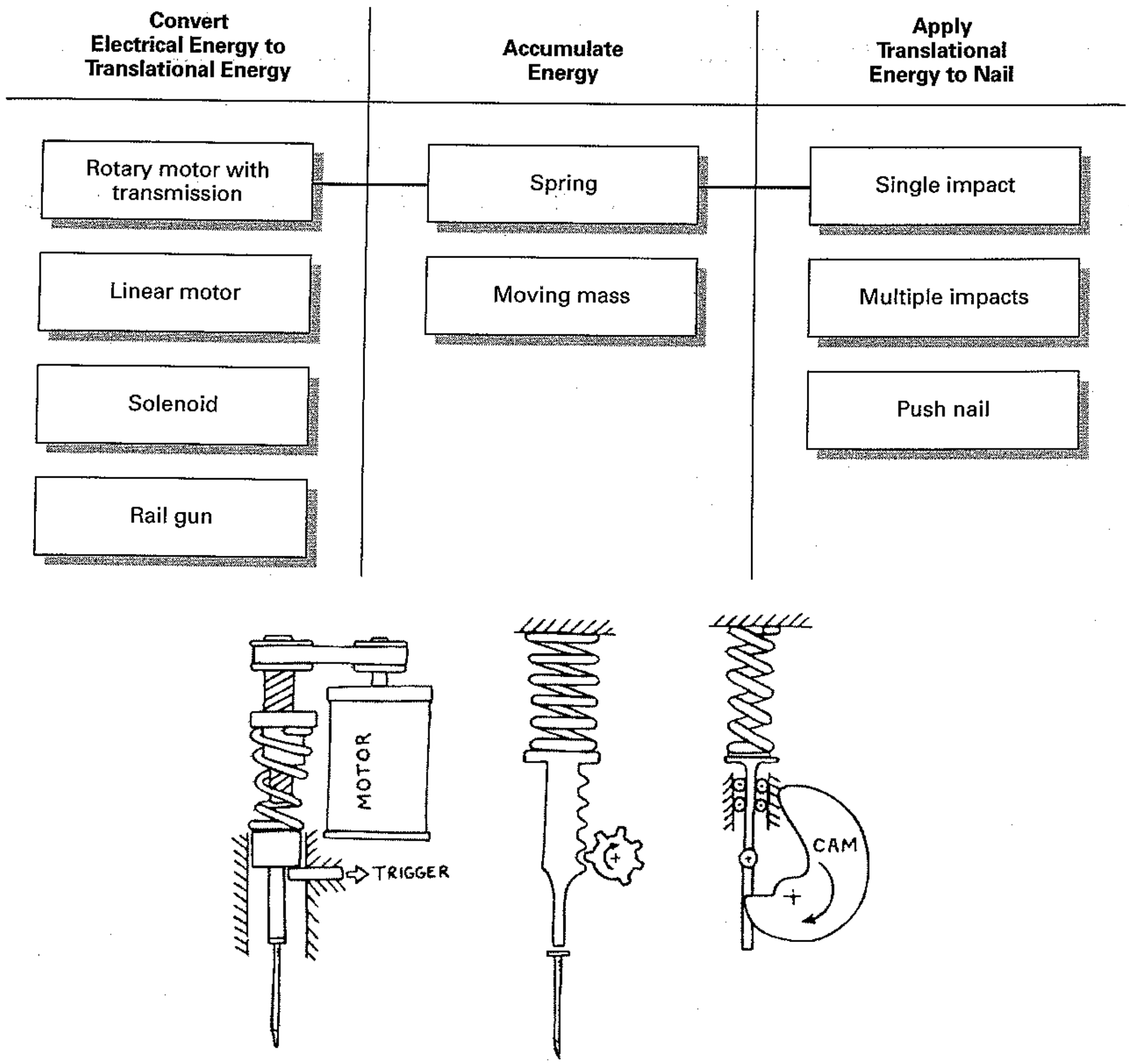


EXHIBIT 6-11 Multiple solutions arising from the combination of a motor with transmission, a spring, and single impact. The motor winds a spring, accumulating potential energy which is then delivered to the nail in a single blow.

Two guidelines make the concept combination process easier. First, if a fragment can be eliminated as being infeasible before combining it with other fragments, then the number of combinations the team needs to consider is dramatically reduced. For example, if the team could determine that the rail gun would not be feasible under any condition, they could reduce the number of combinations from 24 to 18. Second, the concept combination table should be concentrated on the subproblems that are coupled. Coupled subproblems are those whose solutions can be evaluated only in combination with the solutions to other subproblems. For example, the choice of the specific electrical energy source to be used

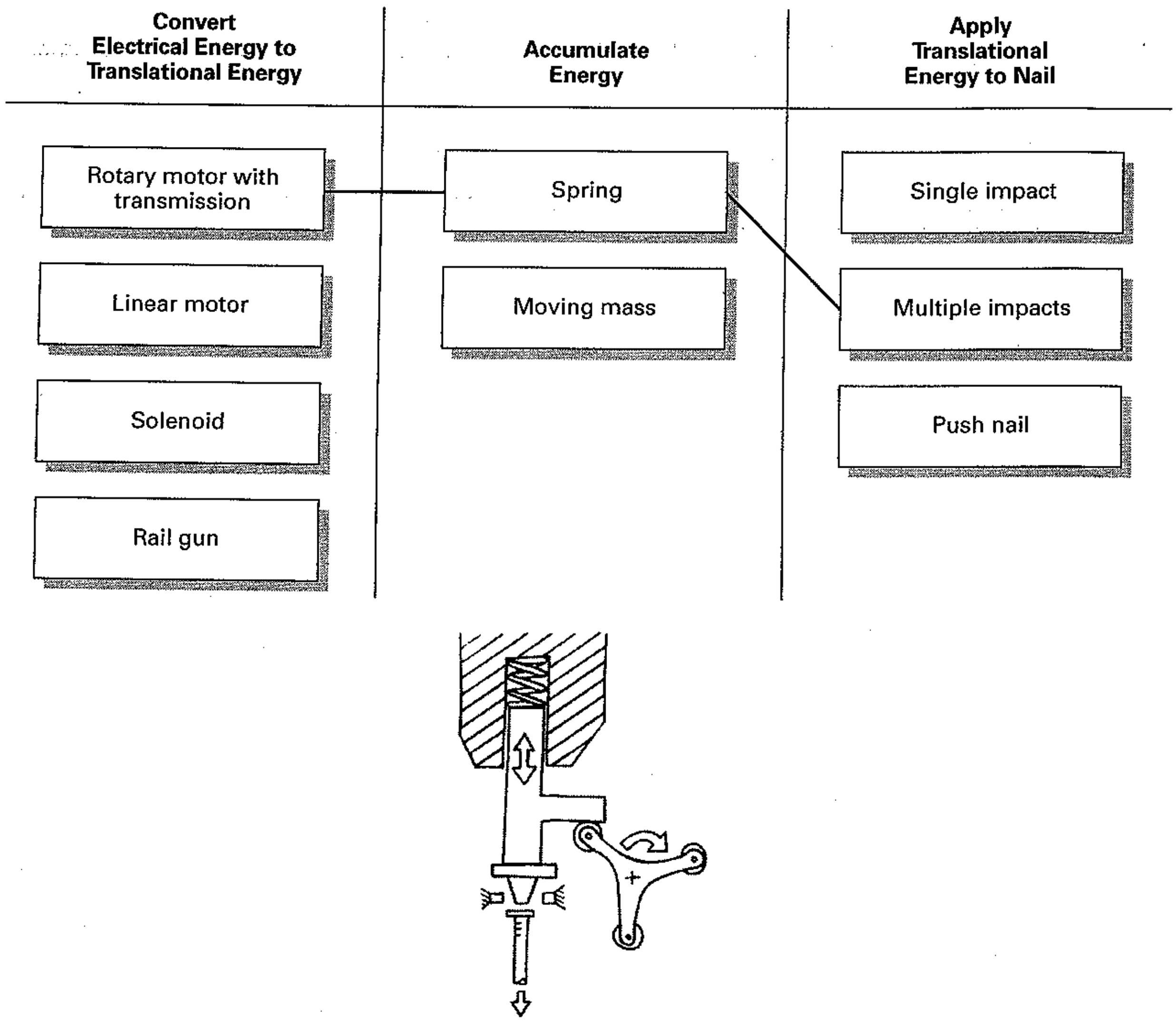


EXHIBIT 6-12 Solution from the combination of a motor with transmission, a spring, and multiple impacts. The motor repeatedly winds and releases the spring, storing and delivering energy over several blows.

(e.g., battery versus wall outlet), although extremely critical, is somewhat independent of the choice of energy conversion (e.g., motor versus solenoid). Therefore, the concept combination table does not need to contain a column for the different types of electrical energy sources. This reduces the number of combinations the team must consider. As a practical matter, concept combination tables lose their usefulness when the number of columns exceeds three or four.

Managing the Exploration Process

The classification tree and combination tables are tools that a team can use somewhat flexibly. They are simple ways to organize thinking and guide the creative energies of the team. Rarely do teams generate only one classification tree and one concept combination table. More typically the team will create several alternative classification trees and several

Convert Electrical Energy to Translational Energy	Accumulate Energy	Apply Translational Energy to Nail
Rotary motor with transmission	Spring	Single impact
Linear motor	Moving mass	Multiple impacts
Solenoid		Push nail
Rail gun		

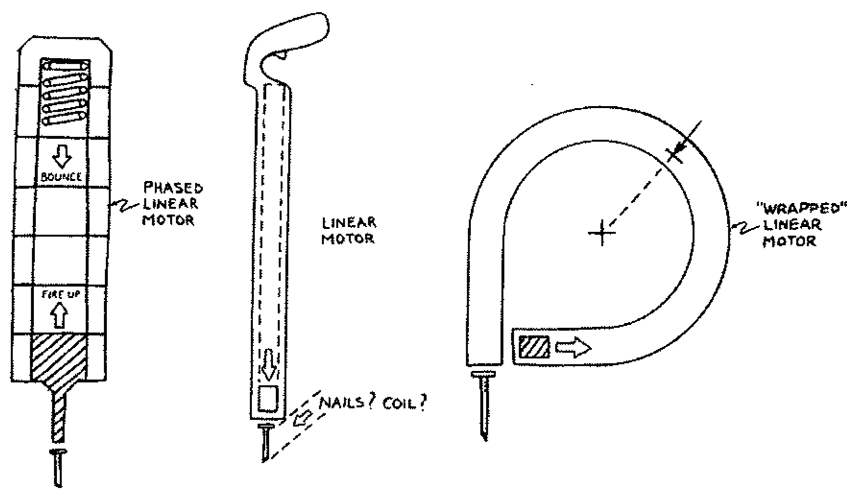
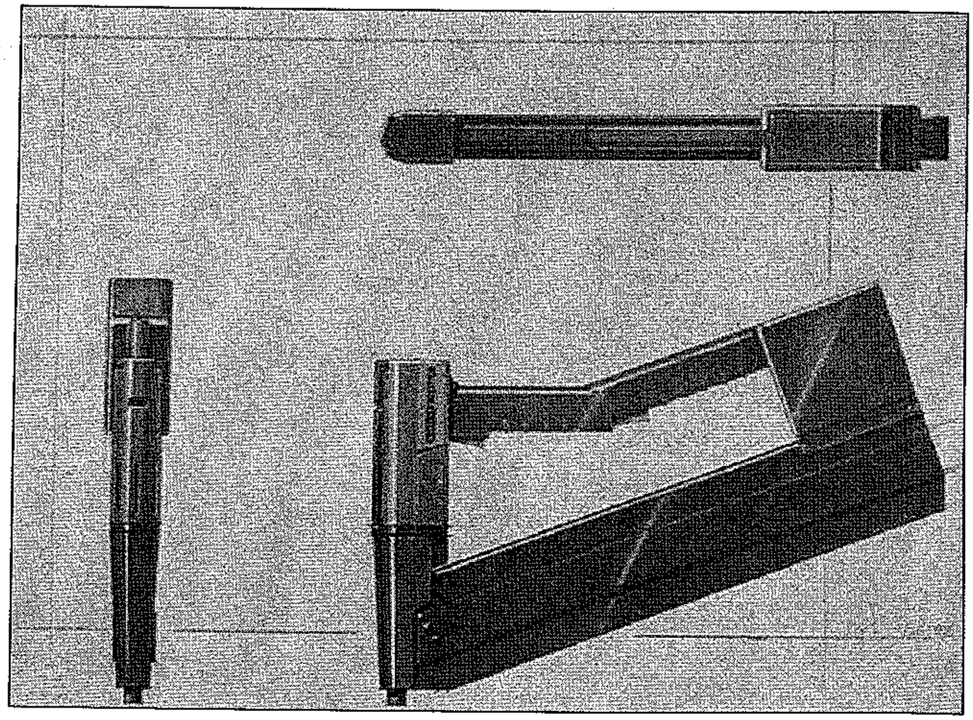


EXHIBIT 6-13 Solutions from the combination of a linear motor, a moving mass, and single impact. A linear motor accelerates a massive hammer, accumulating kinetic energy which is delivered to the nail in a single blow.

concept combination tables. Interspersed with this exploratory activity may be a refining of the original problem decomposition or the pursuit of additional internal or external search. The exploration step of concept generation usually acts more as a guide for further creative thinking than as the final step in the process.

Recall that at the beginning of the process the team chooses a few subproblems on which to focus attention. Eventually the team must return to address all of the subproblems. This usually occurs after the team has narrowed the range of alternatives for the critical subproblems. The nailer team narrowed its alternatives to a few chemical and a few electric concepts and then refined them by working out the user interface, industrial design, and configuration issues. One of the resulting concept descriptions is shown in Exhibit 6-14.

EXHIBIT 6-14
One of several refined solution concepts.



Courtesy of Product Genesis, Inc.

Step 5: Reflect on the Solutions and the Process

Although the reflection step is placed here at the end for convenience in presentation, reflection should in fact be performed throughout the whole process. Questions to ask include:

- Is the team developing confidence that the solution space has been fully explored?
- Are there alternative function diagrams?
- Are there alternative ways to decompose the problem?
- Have external sources been thoroughly pursued?
- Have ideas from everyone been accepted and integrated in the process?

The nailer team members discussed whether they had focused too much attention on the energy storage and conversion issues in the tool while ignoring the user interface and overall configuration. They decided that the energy issues remained at the core of the problem and that their decision to focus on these issues first was justified. They also wondered if they had pursued too many branches of the classification tree. Initially they had pursued electrical, chemical, and pneumatic concepts before ultimately settling on an electric concept. In hindsight, the chemical approach had some obvious safety and customer perception shortcomings (they were exploring the use of explosives as an energy source). They decided that although they liked some aspects of the chemical solution, they should have eliminated it from consideration earlier in the process, allowing more time to pursue some of the more promising branches in greater detail.

The team explored several of these concepts in more detail and built working prototypes of nailers incorporating two fundamentally different directions: (1) a motor winding a spring with energy released in a single blow, and (2) a motor with a rotating mass that repeatedly hit the nail at a rate of about 10 cycles per second until the nail was fully driven. Ultimately, the multiblow tool proved to be the most technically feasible approach and the final product (Exhibit 6-1) was based on this concept.

Summary

A product concept is an approximate description of the technology, working principles, and form of the product. The degree to which a product satisfies customers and can be successfully commercialized depends to a large measure on the quality of the underlying concept.

- The concept generation process begins with a set of customer needs and target specifications and results in a set of product concepts from which the team will make a final selection.
- In most cases, an effective development team will generate hundreds of concepts, of which 5 to 20 will merit serious consideration during the subsequent concept selection activity.
- The concept generation method presented in this chapter consists of five steps:
  1. ***Clarify the problem.*** Understand the problem and decompose it into simpler subproblems.
  2. ***Search externally.*** Gather information from lead users, experts, patents, published literature, and related products.
  3. ***Search internally.*** Use individual and group methods to retrieve and adapt the knowledge of the team.
  4. ***Explore systematically.*** Use classification trees and combination tables to organize the thinking of the team and to synthesize solution fragments.
  5. ***Reflect on the solutions and the process.*** Identify opportunities for improvement in subsequent iterations or future projects.
- Although concept generation is an inherently creative process, teams can benefit from using a structured method. Such an approach allows full exploration of the design space and reduces the chance of oversight in the types of solution concepts considered. It also acts as a map for those team members who are less experienced in design problem solving.
- Despite the linear presentation of the concept generation process in this chapter, the team will likely return to each step of the process several times. Iteration is particularly common when the team is developing a radically new product.
- Professionals who are good at concept generation seem to always be in great demand as team members. Contrary to popular opinion, we believe concept generation is a skill that can be learned and developed.

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www.ulrich-eppinger.net

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Exercises

1. Decompose the problem of designing a new barbecue grill. Try a functional decomposition as well as a decomposition based on the user interactions with the product.
2. Generate 20 concepts for the subproblem "prevent fraying of end of rope" as part of a system for cutting lengths of nylon rope from a spool.
3. Prepare an external-search plan for the problem of permanently applying serial numbers to plastic products.

Thought Questions

1. What are the prospects for computer support for concept generation activities? Can you think of any computer tools that would be especially helpful in this process?
2. What would be the relative advantages and disadvantages of involving actual customers in the concept generation process?
3. For what types of products would the initial focus of the concept generation activity be on the form and user interface of the product and not on the core technology? Describe specific examples.
4. Could you apply the five-step method to an everyday problem like choosing the food for a picnic?
5. Consider the task of generating new concepts for the problem of dealing with leaves on a lawn. How would a plastic-bag manufacturer's assumptions and problem decomposition differ from those of a manufacturer of lawn tools and equipment and from those of a company responsible for maintaining golf courses around the world? Should the context of the firm dictate the way concept generation is approached?