Strategic Management of Scientific Research Organizations

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Abstract

Scientific research organizations and laboratories are increasingly facing strategic challenges, such as climate change and health care, and solutions require enhanced strategic thinking. Learning, through double-loop feedback systems, takes place in scientific research disciplines and engineering fields. Similarly, research organizations can implement strategies within the framework of a double-loop learning system as found in fields of research. Strategic thinking about the performance of research organizations can be enhanced through the use of an innovative conceptual tool called a strategy map. Strategy maps help to make organizational strategies more visible and measurable. This article shows how strategy mapping fits within the larger "double loop" context of a scientific research organization's strategic performance management system and its inherent feedback loops. The article also describes the features of strategy maps and how they can help the leaders of scientific research organizations make strategic decisions and manage more effectively.

Introduction

IN THE MANAGEMENT of scientific research organizations, a nagging question arises: Since the nature of basic research is exploratory, scientists do not know in advance the best way to proceed. If they did, they would pursue that direction and reject the alternatives. Since they do not, research is inherently wasteful of time and resources. This dilemma has been described as one of the "grand challenges" of basic research (Valdez 2001).

Commercial organizations that have a research or innovation department need to justify research budgets by demonstrating fruitful results to their stakeholders. A similar challenge is faced by mission-oriented governmental organizations. The Government Performance and Results Act (GPRA) of 1993 (and its revisions) require all Federal agencies to develop strategic plans and performance measurement plans, in order to justify their funding. Although nonprofit and governmental organizations do not have profit as their mission, they do cost money and are expected to be good stewards of it. Hence it is imperative for all research organizations to learn how to "do more with less."

Dr. Ron Kostoff has studied the management of government research and the process of evaluating that research for several decades. He recommended that "program peer review should be integrated seamlessly into the organization's business operations ... It should not be incorporated in the management tools as an afterthought, as is the case in practice today, but rather should be part of the organization's front-end design" (Kostoff 2003).

As a step in this direction, this article offers an approach for integrating strategy and performance evaluation into a system analogous to that of the scientific research process itself. The article describes a simplified model of the scientific research process in terms of hypothesis testing. Next this model will be applied to an organization's strategic management process, which aims to improve the productivity of research. A "strategy map" is introduced as a tool for the formulation of the organization's strategic hypothesis. This extends what will be described as a "double-loop learning process" to the organization itself, so that its research performance can be evaluated and improved over time.

Scientific Hypothesis Testing as Double-Loop Learning

Science is a learning process which is continuous, unending, and always subject to future revision. Science takes practical steps – sometimes revolutionary, but often incremental – toward more well-tested models. In practice, research does not proceed in a step-by-step fashion; there are many twists and turns, and the activities may occur in a different order or even be separated by many years. Real scientific work involves the "tacit dimension" of research described by Polanyi: "Because it is tacit and not explicit, it is not fully replicable and the establishment of a theory depends on personal insight and peer review within the scientific community" (Polanyi 1967).

Despite the risks of oversimplification, it is evident to the author that scientific hypothesis testing often proceeds via two feedback loops:

a) a loop involving the formulation and revision of hypotheses (with the sequence, hypothesis-prediction-evaluation-revision); and

b) a second loop involving the testing and revision of experiments (with the sequence, experiment-data-evaluation-revision).

Such a "double-loop learning" system involves two interconnected feedback loops (Argyris and Schön 1974). Figure 1 illustrates the double-loop learning process applied to scientific hypothesis testing.

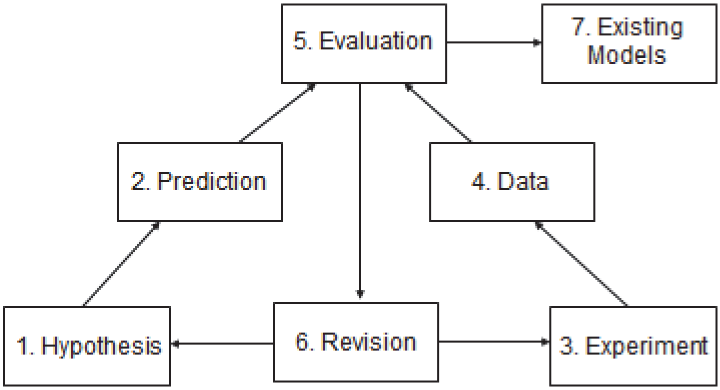

Figure 1. Double-Loop Learning in Scientific Hypothesis Testing

In general, the process includes these types of activities (not steps):

1. **Hypothesis:** A plausible explanation of some natural phenomenon is proposed.
2. **Prediction:** Based on the hypothesis, observable and measurable consequences are deduced.
3. **Experiment:** Activities pertinent to the hypothesis are conducted to test its predictions (e.g., apparatus construction, observations, simulations, documentation).
4. **Data:** Quantitative measurements commensurate with predictions are recorded and processed to reduce uncertainties due to bias, errors and randomness.
5. **Evaluation:** Predictions and data are compared, with due consideration of statistical uncertainties. A successful evaluation requires not only agreement between the data and predictions, but also a determination that excludes other alternative models (Giere *et al*. 1998).
6. **Revision:** An evaluation that fails to show agreement may lead researchers to make revisions in either the hypothesis or

the experiment (*e.g.*, the earlier experiment may not have been sensitive enough, or may not have yielded data commensurate with the predictions).

7. **Existing models:** This activity involves the collection of tested hypotheses and their predictions that have not been falsified so far (Popper 1968).

In Figure 1, the left-hand loop is represented by activities 1, 2, 5, and 6. The right-hand loop is represented by activities 3, 4, 5, and 6.

More "Double-Loop Learning" Examples

There are many examples of systems containing double feedback loops that converge and eventually result in an accumulation of learning. This section provides two examples.

Engineering

The first example is provided by applying the double loop concept to the field of engineering. In engineering, a goal is to arrive at an optimum design for a product or process. The activities involve two loops or groups of actions. The sequence below describes the activities that are repeated using the same pattern of loops and numbered boxes until a prototype is developed that meets specifications, where possible:

1. A prototype design is created based on existing knowledge.
2. It is desired that the prototype will meet certain quantitative design specifications (along with generally desired requirements such as low cost, limits on time to build and maintain, etc.).
3. The prototype is tested under real-world or simulated real-world conditions.
4. Data from the tests are collected and documented.
5. The data are compared with the specifications. If all the specifications are met, the prototype design may move to production.
6. If there is lack of compliance with the specifications, or if the evaluation is inconclusive, revisions are necessary. Either the design must be revised, or additional testing must be done, or both.
7. When all specifications have been met, the process results in an "optimized design" ready for production.

Similar to above, the loops involve these two groups of activities: The first loop involves activities 1, 2, 5, and 6. The second loop involves activities 3, 4, 5, and 6.

Evolution

The field of evolution provides a second example. Existing species of life on earth represent millions of years of continuous confrontation between expressed genes and their environment. In a broad-brush description, the following activities have operated over time (the numbers below correspond to the numbers in the boxes of the double-loop learning process illustrated in Figure 1):

1. A genome, including its mutations and recombinations, is expressed in cells by reproduction.
2. Numerous individual organisms with various phenotypes are produced.
3. Life exists in an environment which contains a variety of changing threats and opportunities.
4. Individuals are exposed to the environment.
5. Depending on their response to features of the environment, individuals are selected for increased or decreased reproduction (natural selection).
6. Mutations continue to occur, and the environment continues to change.
7. At any point in time, the existing life forms are those that have been most successful in reproducing throughout their cumulative exposures to changing environments.

Again, the loops are represented by activities 1, 2, 5, and 6 and activities 3, 4, 5, and 6.

Both of these examples show the same general pattern, as noted: a system of two feedback loops that converge and eventually result in an accumulation of learning.

Double-Loop Learning in Scientific Research Organizations

The above examples serve to suggest the wide range of applications of the double-loop learning system. How can a double-loop system be implemented to manage and evaluate the performance of a scientific research organization?

An organization is a dynamic system: “a set of things … interconnected in such a way that they produce their own pattern of behavior over time" (Meadows 2008). A key feature of dynamic systems is that they contain feedback loops (Nay and Kay 1982, Haines 2000).

Scientific research organizations and their activities can be thought of as having two feedback systems in operation which are analogous to the learning loops described earlier:

a) The inner system is the conduct of scientific research proper, in which success depends on posing insightful hypotheses and focusing on the most promising observations and experiments.

b) The outer system has management challenges similar to those in any other organization. Management in the outer system does not encounter "grand challenges." Here, the organization is trying to enable scientists to conduct research activities more efficiently. Its managers seek strategies for finding the right skills and technology, better ways to organize, better procedures to follow and better ways to evaluate performance. Such improvements help to drive down cost, duplication, and time delays in research.

In most scientific research organizations, more can be done to improve the efficiency of the outer system of management, thereby enabling the inner system of research proper to become more effective, operating with fewer delays and resource shortages. The intent is not to presume to improve scientific research *per se* (which would require specialized expertise in narrow fields of research), but rather to improve the management system supporting that research.

Figure 2 shows a double-loop system with the labels changed so that the context is that of a scientific research organization, as follows:

1. **Strategy:** The scientific research organization's planners formulate a strategic hypothesis: a specific vision and "road map" for achieving it.
2. **Desired results:** Activity 2, desired results, represents the intended long-term improvements in the organization's accomplishments expected from the strategy.
3. **Strategic initiatives:** Activity 3, strategic initiatives, includes new projects and changes in operations and budget allocations that are aimed at improving performance to reach the desired results.
4. **Actual results:** Activity 4, measuring performance or actual results, relates to quantitative and qualitative measurements

of end results but also intermediate results or "leading indicators" that managers can use to forecast longer-term outcomes. An approach for developing these intermediate measures of performance will be presented in the next section.

5. **Evaluation:** Typically, senior leaders in an organization will periodically convene high-level strategy reviews, in which everything is questioned. One of the main questions addressed is the comparison question: Do the data show that desired results were met? Of course it could be that circumstances beyond the organization's control caused the results, or variations in data may make comparisons inconclusive.
6. **Revision:** If the desired results were not achieved, there may be a need to revise the strategic initiatives, how they are measured, allocation of resources, or other activities. Or, the data may indicate a need to revise the strategic hypothesis itself.
7. **Successful strategies:** Over time, the organization learns what strategies are more or less successful, based on measures of strategic performance. Successful strategies embody the knowledge and experience of the organization's leaders.

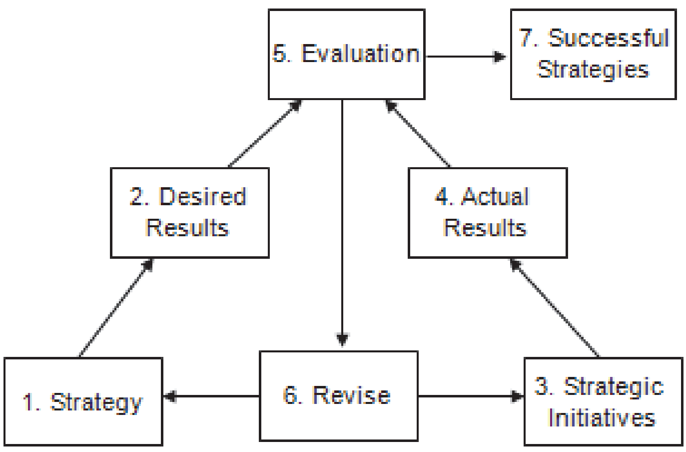

Figure 2. Strategic Management Model for a Scientific Research Organization

The Left-Hand Feedback Loop: Organizational Strategy

The first feedback loop is all about strategy. Scientific research organizations are increasingly facing strategic challenges, such as climate change and health care. Solutions require enhanced strategic thinking.

A scientific research organization must define its strategy (box 1) before it prescribes new strategic initiatives (box 3) or measures performance (box 4). The organization must first establish agreement on the destination, and then propose how to get there. Strategy should come before organization design, budgeting, operational plans, or process improvements – and before establishing key performance indicators or collecting performance measures (Rohm 2002). Performance measurement and evaluation then supports strategic management, not merely operations or compliance (Apple, Inc. 2011). Strategy should set the context for what is considered high or low performance.

A strategy map is a relatively new kind of visual tool that describes an organization's strategic hypothesis (box 1 in Figure 2). A strategy map illustrates a chain of *strategic objectives* drawn as ovals and linked together with arrows that lead to a long-term and strategic desired result for the organization (box 2, desired results, in Figure 2).

The strategy map is becoming a popular management tool because it makes strategic planning more practical and visual. For example, the book *Strategy Maps* (Kaplan and Norton 2004) is devoted entirely to the concept of strategy mapping, and contains examples from a variety of organizations. A strategy map is not an organization chart, flowchart, logic model, work breakdown structure, technology roadmap, system diagram, or program plan.

Figure 3 is a hypothetical strategy map for a scientific research organization. (In practice, no two organizations' strategy maps are alike, but this hypothetical figure illustrates some key features and best practices in strategy mapping). It is recommended that a strategy map be created in facilitated workshops by a diverse, cross-functional planning team within the organization (Rohm 2002).

The four rectangular areas of the strategy map in Figure 3 present four "perspectives" of organizational performance: organizational capacity, internal process, finance, and stakeholder perspectives. These indicators offer a "balanced scorecard" of mostly leading indicators of future organizational performance. The order of the four perspectives of organizational performance is important. Figure 3 shows the proper arrangement of the perspectives for a public sector or non-profit organization. For a private sector organization, the financial perspective would be on top.

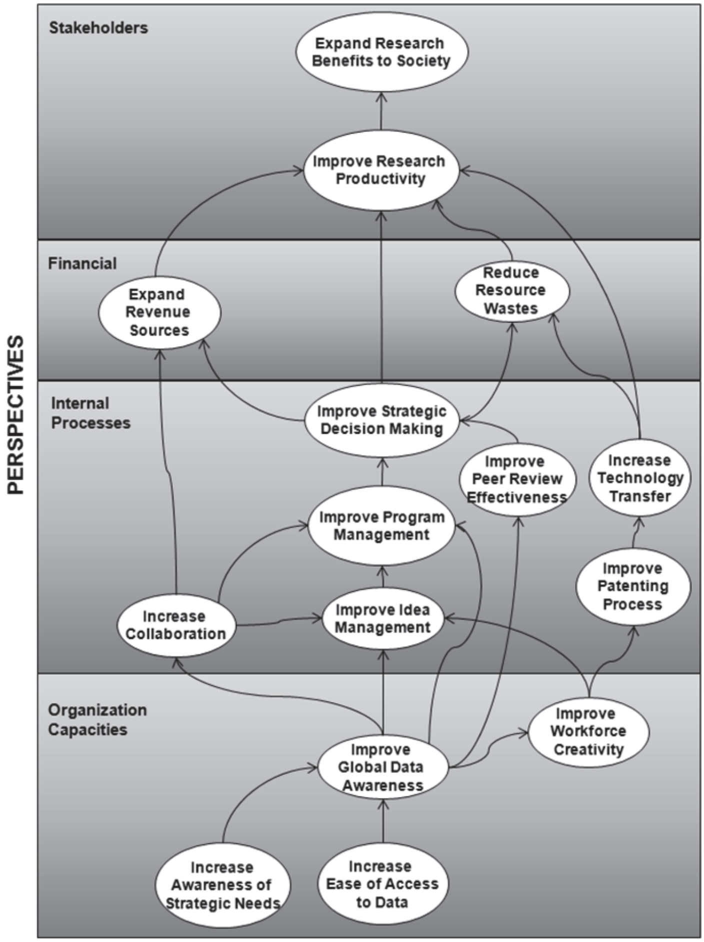

Figure 3. Hypothetical Strategy Map for a Non-profit Research Organization

A strategic objective (each oval on Figure 3) specifies – in a few words – *what* needs to be improved. Each strategic objective begins with an imperative verb that suggests continuous improvement, such as *improve, increase* or *reduce*. Strategic objectives are written in "high-altitude" language. They are not projects; many projects may support improvement of one objective. Further development of the strategic plan is necessary to identify strategic projects that align with the strategic objectives.

The linked strategic objectives form a chain of cause and effect. Following the arrows, the strategy map can be read from the bottom up. The strategy map as a whole prescribes how the intermediate results lead to the final strategic result at the top of the map – which equates to desired results in Figure 2. In this non-profit example, one of the cause-effect chains would read as follows, starting at the bottom:

> *"If we increase ease of access to data, then we will be able to improve global data awareness. This will lead to increased collaboration, internally and externally, and possibly expand revenue sources. It will also allow managers to conduct more effective peer reviews, which will help to improve strategic decision making [e.g., budgeting], which will reduce resource waste and improve research productivity, ultimately expanding research benefits to society.*

Another cause-effect chain from the same strategy map would read as follows, starting at a different place in the bottom quadrant:

> *If we improve workforce creativity [e.g. by hiring smart people and placing them in teams], this will improve idea management and/or patenting processes, which will lead to increased technology transfer and improved research productivity. The end result will be to expand research benefits to society."*

Notice that all the "roads" on the strategy map go in one direction only. Strategy maps provide a one-way road map. *There are no backward paths or feedback loops on a strategy map*, for why would anyone want to propose efforts that go against achieving the strategic results?

Within the context of strategic planning, the strategy map addresses the question, "Are we doing the right things?" in contrast to the operational question, "Are we doing things right?"

People who study system dynamics tend to see strategy maps as incomplete because they are missing feedback loops (Akkermans and van Oorschot 2002; Bianchi and Montemaggiore 2008; Kim *et al*. 2006; Linard and Dvorsky 2001). However, a strategy map is not intended to be a description of an organization's systems or processes or dynamics or external environment. Instead, a strategy map is a *piece* of the system (the "hypothesis" box and desired results box), not the whole system. There is a proper place for feedback, but it is not on the strategy map; rather, it is within the double-loop strategic management system illustrated in Figure 2.

The basic framework of the four "perspectives" introduced by Kaplan and Norton (1993) is a robust, generally-applicable framework for strategy mapping. It is also scalable – it can serve the planning needs of small non-profits, huge multinational corporations, or large government agencies. The U.S. Army and other military branches are increasingly adopting strategy mapping. Most importantly, in terms of the subject of this article, strategy maps are also applicable to scientific research organizations.

The Right-Hand Feedback Loop: Measuring the Strategy

Earlier approaches to organization improvement and performance measurement, such as Total Quality Management (TQM) and Six Sigma methods, do not fit well within a scientific research organization which does not have repetitive manufacturing processes or tangible products. Application of such methods in research organizations often results in measuring the wrong things and "measurement fatigue" because the focus tends to be on operational rather than *strategic* performance measures.

How can managers of scientific research organizations identify strategic performance indicators? *They are simply the strategic objectives on the strategy map that are being "improved," "increased," "reduced," etc*. These are the intermediate results (according to the planning team) most likely to lead to the "desired results" (box 2 on Figure 2). Once strategic objectives are defined in the ovals on the strategy map, strategic performance indicators to measure these objectives follow directly.

So-called "intangible" or qualitative metrics are often needed. For example, to measure the strategic objective, "Increase ease of access to data," the measurement may involve a survey to determine the level of complaints or delays in data access. To measure the strategic objective "Increase strategic decision making," it may be necessary to conduct structured interviews of managers to assess their awareness of the strategic plan and how they are using it to make decisions.

If measurement is defined as "observations that reduce our uncertainty in the value of a quantity," then anything real can be measured (Hubbard 2010). Kostoff (2005) recognized that gathering useful research metrics may require technical tools such as large databases, automated text data mining, bibliometrics, *etc*. – the "information infrastructure" that managers can put in place to enable scientists to compile information efficiently. But in the case of scientific research programs, qualitative measures, including peer review, are often more meaningful than quantitative measures. Kostoff (1997) argued that peer review is a necessary, if not sufficient procedure for the evaluation of scientific research programs. Hence some federal research agencies have been permitted to provide qualitative program assessments to the Office of Management and Budget, not merely numerical data.

Peer review serves to maintain the focus of a project or program, build credibility and share lessons learned, according to Dr. Daniel Lehman, Director of the Office of Project Assessment in the Office of Science at the U.S. Department of Energy (Lehman 2011). However, peer review can be costly and time-constrained because there are often few qualified peers. Therefore, certain considerations must go into the design of an effective program peer review (Kostoff 2003). Nay and Kay (1982) offer an important preliminary consideration: Has the program been implemented to the extent that it can be evaluated?

As strategies are evaluated (box 5 on Figure 2), feedback comes through the double-loop learning system. Through regular, periodic evaluations of strategic performance, the strategy – including strategic objectives, performance measures derived from the strategic objectives, strategic initiatives, and even budgets – can be revised. This management system establishes a balance between consistency of the desired strategic result(s) and flexibility of management decision-making based on the feedback loops.

Conclusion

Physicists have a saying, "Many a beautiful theory has been destroyed by one ugly fact." In an organization, "ugly facts" represent unequivocal performance data confronting executives and board members.

The leaders of strategy-focused organizations, however, will have a head start on dealing with performance data through: (1) a double feedback loop approach to strategic performance management; and (2) a strategy map with performance measures for each of the strategic objectives. The strategy map will include customer (or stakeholder) feedback data, as well as measures of financial costs, internal process efficiencies and organization capacities – all leading indicators of future results. Weaknesses in these strategic performance measures can guide the leaders of research organizations to make informed decisions about what specifically needs to be revised to improve strategic performance. Over time, such a management system is designed to encourage innovative strategies and initiatives to improve research effectiveness and productivity (box 7, successful strategies).

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Bio

Paul Arveson's first career was as a physicist in the civilian Navy. He managed projects in acoustics, oceanography, signal processing and analysis, and published numerous technical papers in these fields. In the 1990s, he earned a Master's degree in Computer System Management and a CIO Certificate from the National Defense University. In 1998, he partnered with Howard Rohm to create the Balanced Scorecard Institute which provides strategic management training and consulting services to all kinds of organizations.