

**Highly Innovative Research Teams:
The Case of the Biological Computer Laboratory**

**Stuart A. Umpleby
Frank T. Anbari
Karl H. Müller**

**Published in *An Unfinished Revolution? Heinz von Foerster and the Biological
Computer Laboratory 1958-1976*, Vienna: Ecoraum, 2007, pp. 189-209**

Highly Innovative Research Teams:

The Biological Computer Laboratory (BCL)¹

Stuart A. Umpleby

Frank T. Anbari

Karl H. Müller

The article has been divided into three sections and proceeds from general insights and observations in innovation research across firms and scientific institutes to a narrower focus on radical innovations in science and their organizational environments and concludes with a specific example, namely Heinz von Foerster's Biological Computer Laboratory at the University of Illinois in Urbana which in the short period of its existence between 1958 and 1975 exhibited a large number of essential characteristics for radically innovative research. In fact, it is astonishing in retrospect that Heinz von Foerster shaped the organizational design of the BCL in a way which nowadays seems to be the most promising and most fruitful configuration for a permanent proliferation of highly innovative and, at times, also highly implausible and counter-intuitive ideas, theories, mechanisms or instruments.

1 Research, Innovation and Organization: The Managerial Perspective

As a starting point, a quick overview will be presented on the existing literature on management and innovations, starting with necessary features within organizations and ending with important requirements for successful co-operations between teams across different organizations.

1.1 Internal Organizational Factors for Innovative Research

One of the primary problems with respect to high performing or very innovative research teams² lies in their requisite homogeneity or heterogeneity. Morgan, *et al.* (1976) investigated questions concerning the effects of members' heterogeneity on R & D team effectiveness at the research

¹ Large sections of the first and the third part of this article have been published by Anbari/Umpleby in the year 2005 and revised for the present volume, the second part has been added by Karl H. Müller.

² The innovative performance of companies has been studied extensively. However, studies have not yet led to a generally accepted indicator or a common set of indicators of innovative performance, in view of the substantial variation of constructs, measurements, samples, industries and countries. Hagedoorn & Cloudt (2003) studied the innovative performance of a large international sample of nearly 1,200 companies in four high-tech industries, using four R&D indicators: inputs, patent counts, patent citations, and new product announcements. They established that a composite construct based on these four indicators clearly catches the innovative performance variable, but they also found a strong statistical overlap among these indicators. Greve (2003) proposed a model of innovation development and launch based on the behavioral theory of the firm. Traditionally, the performance of new product development projects has been assessed by R&D or project managers. Rarely have researchers sought customers' points of view. For integrating the customers's side as well see Sicotte, *et al.* (2004).

and development center of a major industrial organization organized into 16 product-line groups engaged in the development of plastics, polymers, and production processes. The sixteen teams were split into two groups based on the rank ordering of judges, and the eight most effective teams were compared to the eight least effective teams. The results indicated that members of the more effective teams experienced more satisfaction of their professional needs, were seen as better individual performers by the center, were better educated, were more attached to their teams, and perceived their teams to be more willing to take risks based on knowledge. On average the more effective teams were composed of better individual performers. Also, the more effective teams were more homogeneous than the less effective teams, in general. The more effective teams were characterized by greater homogeneity among their members with respect to opportunities to fulfill professional and self-actualization needs, involvement in one's job, and the date when the B.S. degree was received. At the same time, team effectiveness correlated positively with heterogeneity as to open, authentic communication, tenure at the center, and need for status. Apparently, these results indicate that research teams are most successful if a proper mix between homogeneity and heterogeneity can be maintained.

Turning to another set of essential characteristics for high-performing systems Vail (1982) claimed that they have a number of common characteristics:

- 1) clarification of broad purposes and near-term objectives,
- 2) commitment to purposes,
- 3) teamwork focused on the task at hand,
- 4) strong and clear leadership, and 5) generation of inventions and new methods.

Vaill (1982) defined "purposing" as a continuous stream of actions by leaders of human systems that has the effect of inducing clarity, consensus, and commitment concerning the organization's basic purposes. He described the personal qualities that enable leaders of high performing systems to define and maintain a clear sense of purpose among all system members. He said that such leaders are willing to invest large amounts of time in the system, have the ability to develop and express deep feeling about the system, its purposes, the people in it, its history, and its future. Such leaders are able to focus on the issues and variables in the system that make the difference in its performance.

Regarding product development, Lester (1998) argued that the success of a new product development effort hinges on critical factors in five areas:

- 1) senior management commitment, which is a key prerequisite for success,
- 2) organizational structure and processes that support the venture,
- 3) attractive new product concepts being available for development,

4) venture teams with appropriate staffing and resources able to communicate effectively with management and markets, and

5) project management able to focus on reducing uncertainties as early as possible.

He claimed that attention to these factors during the early stages of new product development allows managers to save significant time and money while reducing delays and risks.

Based on action research with product development and project teams from four companies, Eppler and Sukowski (2000) proposed a model of how team leaders can improve knowledge management within their teams. The model consists of five layers:

1) necessary communication platforms for a team,

2) team rules, goals, and standards,

3) core team knowledge processes,

4) relevant tools, and

5) necessary leadership functions to foster effective team knowledge management.

Hence, from the extensive management literature on innovation teams within an organization one can extract a number of common factors like a proper mix of homogeneity and heterogeneity in the team composition, communication platforms, leadership and commitment to a strategic vision plus a supportive team-environment.

1.2 External Factors for Innovative Research: Co-operations and Networks

Turning to essential factors for high performance co-operations between different organizations Carayannis and Laget (2004) maintain that collaborative, team-based research is becoming the most significant mode of research activity in the global scientific community, where groups of researchers involved in scientific progress often span one or more nations in origin, location and/or sponsorship. They highlight the recent trend of cross-sectoral cooperation in scientific collaboration, where researchers in a group are employed by government, private industry, and/or academic and other non-profit institutions. They provide evidence that collaboration in scientific research is increasingly global in nature, by analyzing historical data on co-authorship of scientific publications and examination of the scale (volume of co-authored papers), intensity (co-authored papers versus other kinds of co-authorship), and scope (patterns in co-authorship) for cross-national, cross-sectoral collaborations.

Moreover, research and innovation are enhanced by continual knowledge sharing. Knorr-Cetina and Bruegger (2001) argued that information technology may make an organization less cumbersome by exteriorizing organizational processes on screen, making them transparent, and self-changing. By being exteriorized, knowledge is kept current, alive and distributed in the

respective organizations, and is effectively precluded from becoming implicit and embodied in places and persons. This form of coordination is a content-driven, knowledge-enhancing activity rather than being based on social authority, governing and deciding.

Miotti and Sachwald (2003) developed an integrated framework to examine the determinants of the choice of partners with which firms cooperate on R&D. They underscore the interactions between three major questions: why cooperate, who does, and with whom? They argue that the choice of partners is dictated by the complementary resources which the partners command. They propose a framework to predict the relative efficiency of R&D cooperation with different partners, including suppliers, clients, rivals, academic institutions, and foreign firms.

Additionally, Hage and Hollingsworth (2000) indicated that variation in commercially successful radical product and process innovations among science-based industrial sectors can be explored by focusing on idea innovation networks. These networks operate in six arenas: basic research, applied research, product development research, production research, quality control research, and commercialization/marketing research. Hage and Hollingsworth (2000) argue that the greater the diversity of competencies or knowledge that is connected with frequent and intense communication within an arena and the greater the size of the arena, the greater the likelihood that radical innovations will emerge. They further argue that if radical solutions are to occur in more than one arena, there must be intense and frequent communication among the different arenas involving radically new ways of thinking. Both tacit knowledge and codified knowledge need to be communicated across arenas. Radical research solutions in one arena often involve tacit knowledge that must be effectively communicated to another arena. Communication of tacit knowledge is more likely to occur when there is frequent and intense communication across arenas.

Finally, Amabile, *et al.* (2001) studied the extent to which, and the ways in which, the success of cross-profession collaboration is influenced by

- 1) collaborative team characteristics,
- 2) collaboration environment characteristics, and
- 3) collaboration processes.

Their examination of the Innovation Research Group (IRG) revealed that among collaborative team characteristics, incompatibility of problem-solving styles appeared to lead to unproductive process conflict, that leader skill in managing team communications appeared to strongly influence the team's functioning, and that cultural differences between the academics and the practitioners in the IRG were frequently mentioned as the culprits behind process conflict. Among collaboration environment characteristics, the question of institutional support for each collaborator appeared prominently. Among collaboration processes, effective use of member

capabilities and frequent meetings, well planned in advance, appeared to facilitate the functioning of the IRG and the success of its project.

Their study highlighted the important role of conflict resolution processes. Members of the IRG reported that facilitation of team meetings by practitioners experienced in such processes was extremely instrumental in channeling the productive conflicts over ideas and controlling the negative conflicts over processes. Process conflicts were also managed more effectively once the team instituted regular self-examinations of team effectiveness. They argued that conflicts may be especially likely to arise when individuals from different backgrounds and cultures (academia and business) attempt to work closely together. Thus, conflict resolution processes may be particularly important. Frequent, formal, well-planned communication may also play a special role, given that the members of such teams are seldom co-located. Since team members come from different organizations, institutional support may be particularly important to the team's success. Amabile, *et al.* (2001) made several recommendations to others contemplating forming an academic-practitioner research team:

- 1) Carefully select academics and practitioners for diverse, complementary skills and backgrounds with a common core of research knowledge, motivation toward the project, similar views on the value of research, and a willingness to work with people of different styles and professional cultures.
- 2) Clarify commitments, roles, responsibilities, and expectations at the outset, and continually update them as they evolve. Clearly establish the role of the team leader.
- 3) Establish regular, facilitated communication, especially if team members are not located in the same place.
- 4) Find ways for the academics and practitioners to get to know and trust each other as people and to understand their possible cultural differences.
- 5) As a group, occasionally examine the effectiveness of the team's functioning. Set aside a specific time for the team to reflect on itself and explicitly discuss task, process, and relationship conflicts. Use facilitators to help the team productively manage the conflicts that arise.
- 6) Ensure that academics' and practitioners' institutions will be supportive of their involvement.

Effective use of cross-cultural research teams can provide a source of experience and innovative thinking to enhance team performance and the competitive position of organizations. However, cultural differences and related emotions can interfere with the successful completion of research projects. Cultural differences can be either a source of difficulties and miscommunication, or a source of creativity and enlarged perspectives (Anbari, *et al.*, 2003). A multi-cultural research project team can succeed through culturally-aware leadership, effective cross-cultural communication, mutual respect, and reconciliation. Without them, it is likely to fail.

2 Radical Breakthroughs in Science and Organizational Designs

This short review of the literature on the management of innovations has revealed a number of features which are needed for high performance or high innovation teams within or between organizations, be they science-based or economic in nature. These key factors include a delicate balance between homogeneity and heterogeneity, many means of communication and conflict resolution, and leadership or a strong commitment to a strategic vision. It will become the task within this section, to test whether this set of essential conditions is also necessary for a particular branch of innovation activities, namely for radical scientific breakthroughs which, in both the traditional and post-traditional philosophy of science programs, lie at the core of the scientific enterprise.

The subsequent remarks are mostly based on the path-breaking research by J. Rogers Hollingsworth, Ellen Jane Hollingsworth and Jerry Hage³ who studied radical scientific breakthroughs intensively over a period of ten years. With respect to the central notion of a radical breakthrough, Hollingsworth relied on the existing scientific award system. It must be emphasized, though, that Hollingsworth was very careful in selecting a number of criteria and a relatively wide set of major prizes so that major discoveries or radical breakthroughs are not exclusively tied to Nobel Laureates only.⁴

J. Rogers Hollingsworth and Ellen Jane Hollingsworth introduced seven main characteristics of the organizational design of research units, namely scientific diversity, depth, differentiation, hierarchical and bureaucratic co-ordination, integration of multi-disciplinary perspectives, visionary leadership and quality. Each of these areas can be captured by a number of dimensions which are summarized in Table 1.

Table 1 Main Components and Dimensions of an Organizational Design

Main Components	Dimensions
-----------------	------------

³ On this particular research see Hollingsworth/Hollingsworth 2000, Hollingsworth/Hollingsworth/Hage 2006. On the institutionalist and socio-economic background of this approach, see Hollingsworth/Müller/Hollingsworth 2002, Hollingsworth/Boyer 1997 or Hollingsworth/Schmitter/Streeck 1994. And on the general background in innovation theory, see Müller 2000.

⁴ These criteria included: (1) advances in biomedical science, awarded with the Copley Medal by the Royal Society of London (since 1901), (2) discoveries resulting in a Nobel Prize in Physiology or Medicine since the first award in 1901, (3) breakthroughs with a high relevance for bio-medical sciences which yielded a Nobel Prize in Chemistry since 1901, (4) achievements resulting in ten nominations in any three years prior to 1941 for a Nobel Prize in Physiology or Medicine, or in Chemistry, (5) innovations which were found on the shortlists of the commissions of the Royal Swedish Academy of Sciences and the Karolinska Institute of prizeworthy contributions (prior to 1941), (6) discoveries which received the Arthur and Mary Lasker Prize for basic biomedical science since 1961, (7) breakthroughs which were awarded the Gross Horwitz Prize in basic biomedical science, and (8) advances which resulted in the Crafoord Prize by the Royal Swedish Academy of Sciences.

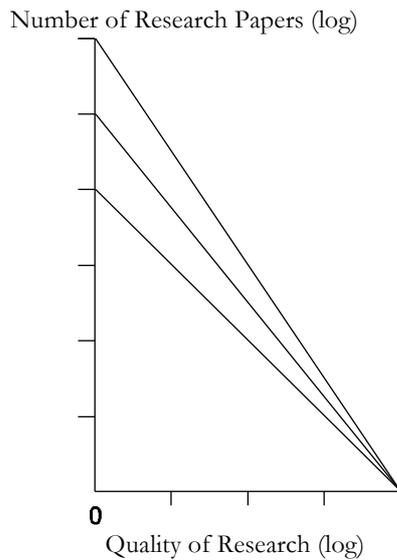
Scientific Diversity	The variety of disciplines, specialties and sub-specialties, proportion of people with research experience in different disciplines and/or paradigms
Depth	Number of scientists in each area of diversity, diversity of talents in each scientific area
Differentiation*	The number of departments and other kinds of units, delegation of recruitment to department or other subunit, responsibility for extramural funding at departmental or other subunit level
Hierarchical and Bureaucratic Coordination	Standardization of rules/procedures, centralized budgetary controls, centralized decision-making about research programs, centralized decision-making about number of personnel
Integration of Multi-disciplinary Perspectives*	Across specialties, the frequency and intensity of interactions, joint publication of papers, existence of journal clubs, sharing of meals and leisure time activities
Visionary Leadership	Capacity for understanding direction in which scientific research is moving and integrating scientific diversity, strategic vision for integrating diverse areas and for providing focused research, ability to secure funding for these activities, ability to conduct recruitment of sufficiently diverse personnel so research groups are constantly aware of what are significant and “doable” problems, ability to provide rigorous criticism in a nurturing environment.
Quality	Proportion of scientists in the nation’s most prestigious academy of science, research funding per scientist.

* At department level: “Research group” should be substituted for “department”

Applying the above criteria for radical breakthroughs and the main components for organizational design, Hollingsworth and his co-workers were able to produce two astonishing general results.

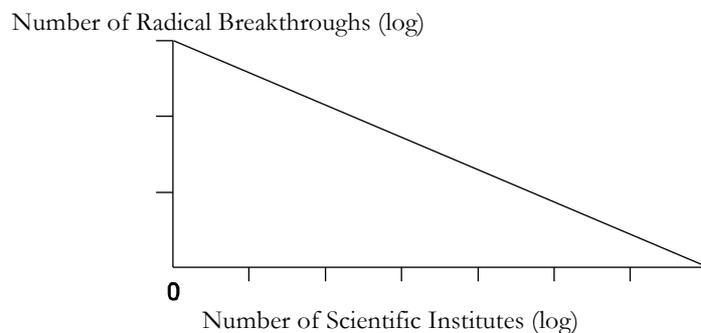
The first discovery on major discoveries was the shape of the relationship between breakthroughs and institutes. The empirical distribution strongly supported a normally overlooked conjecture by Nicholas Rescher (1982) on the underlying relationships between the quantity and the quality of research. Diagram 1 reproduces Rescher’s conjecture which states, essentially, that due to the logarithmic scales any marginal increase in new output of high quality has to be accompanied by increasing the number of papers by a factor of 10.

Diagram 1 A Power-law Relationship between Quantity and Quality of Research



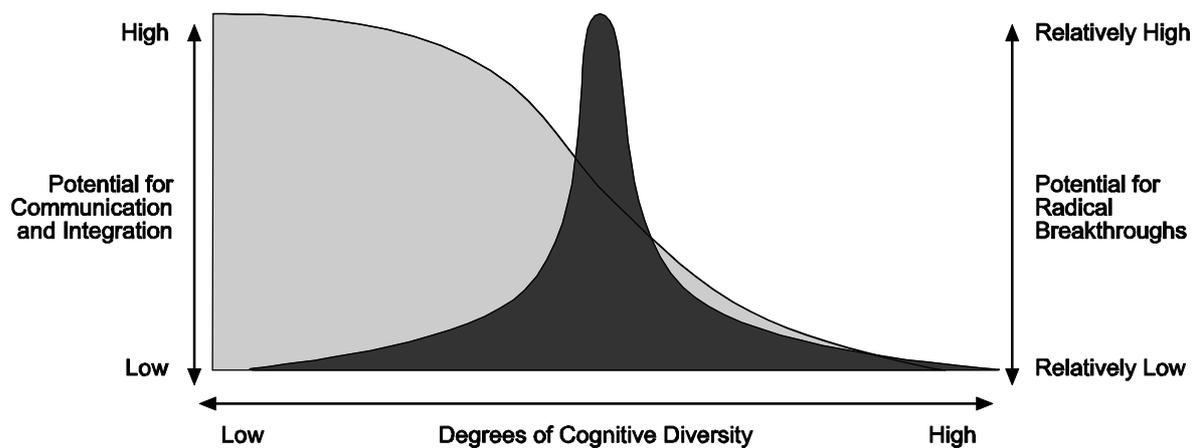
In the case of radical breakthroughs, the horizontal axis stands for the number of scientific institutes in which major breakthroughs occurred and the vertical axis symbolizes the number of radical breakthroughs. Following Diagram 2 one arrives at the conclusion of one of Hollingsworth's lecture titles, namely that some institutes make many major discoveries, but most of the institutes don't.

Diagram 2 A Power-law Distribution for Radical Breakthroughs



The second major discovery of Hollingsworth and his colleagues was achieved through a careful organizational analysis, contrasting the small number of highly innovative research institutes over a long period of time with a second group of institutes which, according to conventional standards of excellence, can be regarded as high quality ensembles which, however, were not able to score on radical breakthroughs. Diagram 3 exhibits the major organizational requirement for a high production of radical breakthroughs, namely a capacity to integrate a medium degree of cognitive diversity, expressed in the number of scientific fields and specialties within an institute, with a maximum amount of communication and social integration, given a particular level of cognitive diversity.

Diagram 3 The Probability Distribution for Radical Breakthroughs



From this general insight, J. Rogers Hollingsworth and his co-workers derived the organizational design both for highly innovative units and their mainstream counterparts whose scientific output can be characterized as normal problem-solving activities. Figure 4a shows the main characteristics of highly innovative research organizations. As one can see, these institutes are characterized above all by

- a weak external environment
- the absence of external controls
- a medium degree of cognitive diversity
- a high degree of social and communicative integration

It should be emphasized however, that the key factors for radically innovative ensembles are linked with one another in a volatile and unstable configuration, as depicted especially in Diagram 3. Why unstable? Simply because there are a number of factors operating on highly innovative units to increase in size, in cognitive diversity or in bureaucratic coordination, which exert a permanent pressure to move away from its current state. In other words, there is a clear tendency in the organizational design of highly innovative research units towards growth, hierarchies, bureaucratic coordination and differentiation, which, however, undermine its previous successes.

Finally, Diagram 4b represents the main characteristics of research organizations, which despite their scientific excellence, have not recorded major discoveries or breakthroughs.⁵

As the contrast between Diagrams 4a and 4b suggests, the main differences lie in the absence or presence of a small number of key factors which, moreover, are distributed across two different levels. At the level of the overall research organization, the key differentiating factors include these elements.

⁵ Typical examples include, following J. Rogers Hollingsworth, the Kaiser Wilhelm-Institute for Biology, the Kaiser Wilhelm Institute for Leather Research, the Max Planck Institute for Cell Physiology or the Institute Pasteur from 1920 to the early 1950s.

- Hierarchies and bureaucratic procedures belong to a class of important distinguishing components, being high in non-innovative settings and low in radically innovative ones. Likewise, organizational flexibility is low in non-innovative research environments and high in innovative contexts.
- Diversity refers to the number of different research fields and is at medium levels in radically innovative organizations and typically too low or too high in non-innovative ensembles.
- D-leadership, as the top-level capacity for coping and managing diversity within the entire research organization, is usually high in the case of very innovative organizations and low in non-innovative units.
- Social integration (S-integration) constitutes probably the most important differentiating component in the set of key factors because one usually finds high social integration in research organizations with a considerable number of radical breakthroughs and medium to low levels of social integration otherwise. Moreover, social integration serves as pre-condition for mutual trust and mutual learning
- Novelty integration (N-integration), understood as the capacity of an entire research organization to deal with novelty and, above all, to be able to integrate it within the normal work agenda, is, once again, high in the case of very innovative units and low in the second group.
- Diversity recruitment (D-recruitment), summarizing the ability of a research organization as a whole to rely on a constant inflow of new personnel with diverse cognitive backgrounds when compared to the already available distribution of cognitive skills and expertise, figures high in the innovative group and low in the second cluster of research organizations.
- Finally, both groups of research institutes turn out to be different with respect to their embeddedness in the wider institutional or spatial environment.

At the level of the laboratories, the five principal organizational components which differentiate between the two groups of research units can be summarized in the following way.

- Scientific diversity turns out to be, once again, relatively high in the case of innovative labs and low to medium in the group with no radical breakthroughs.
- The Network-scope, as the sum of informal or formal ties with scientific groups outside one's own lab, turns out to be broad and diverse for innovative units and narrow and specialized in the case of non-innovative ones.
- Risk-funds, defined as the availability of research funding for uncertain, but doable long-term research, is high in the case of innovative labs and low in labs with no radical innovations.
- Diversity-leadership (D-leadership), capturing the capacity of the head of a lab to manage diversity, is, not surprisingly, high in innovative labs and low in non-innovative ones.

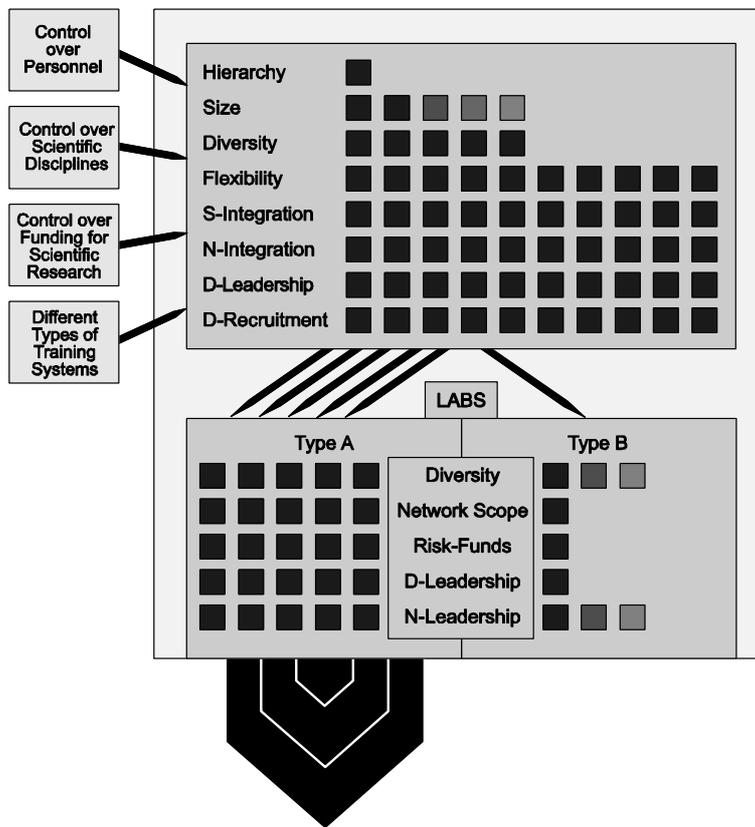
- Novelty-leadership (N-leadership), conceptualized as the ability to recognize novelties as well as to implement them at the lab-level, is typically high in radically innovative labs and low in their non-innovative counterparts.

Diagram 4

The Organizational Design for High and Low Innovations

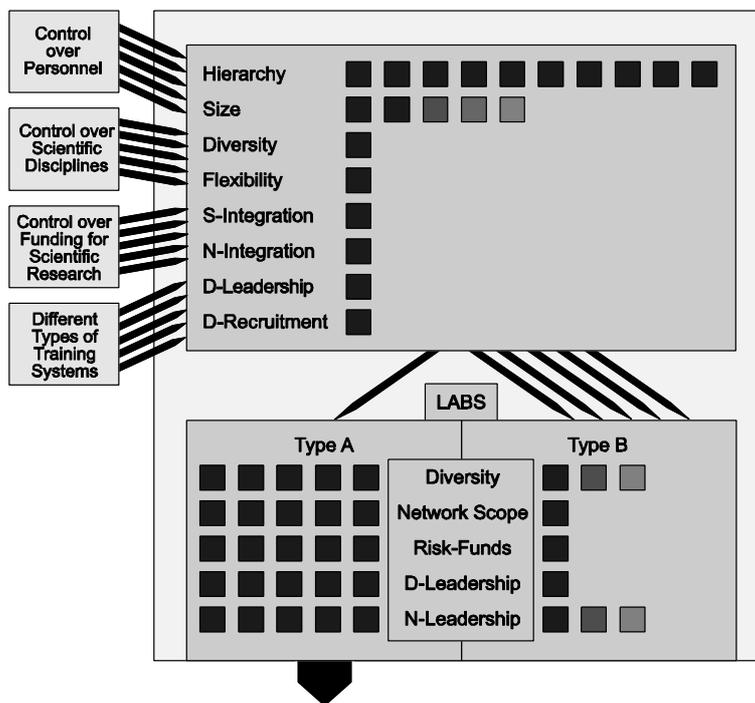
4a

The Highly Innovative Institutional Design



4b

The Design for Marginal Probabilities for Radical Breakthroughs



One of the interesting points in this analysis lies in the high degree of similarity between the general findings in the first part of the article and the pattern of organizational factors which emerges in the Hollingsworth studies. The task in the final part of the article will be to examine how Heinz von Foerster's laboratory scored on the organizational design for highly innovative research units.

3 The Biological Computer Laboratory

One way to evaluate the success of a research center is by how often its work is cited after the center closes. By this standard the Biological Computer Laboratory (BCL) at the University of Illinois in Urbana-Champaign was an outstanding success. BCL operated from 1958 to 1975 under 25 grants and produced 256 articles and books, 14 masters theses and 28 doctoral dissertations in the fields of epistemology, logic, neurophysiology, theory of computing, electronic music and automated instruction. (Biological Computer Laboratory, 2004). Thirty years after it closed, its work is increasingly cited in publications in several countries. The director of BCL was Heinz von Foerster, an immigrant from Austria. What did von Foerster do to create and sustain such a highly productive research team? We describe several features of BCL and the courses that von Foerster taught. These characteristics turn out to be, once again, similar to the points made in the general literature review as well in the extensive breakthrough studies by J. Rogers Hollingsworth, *et al.*

3.1 Scientific Diversity

Interdisciplinary Research

The research at BCL was an extension of the Macy Foundation meetings that were held in the late 1940s and early 1950s on the subject of "circular causal and feedback mechanisms in biological and social systems." (Heims, 1991, Pias 2003/2004). Accordingly, the research agenda at BCL included control and communication processes in any field. The result was a highly interdisciplinary group of faculty members and students. They came from engineering, the biological sciences, mathematics, music, and the social sciences.

Involvement of People at Several Levels of Education

Von Foerster's classes were always about some new area of research, for example bionics, heuristics or cybernetics of cybernetics. The class was a learning exercise for all concerned -- faculty as well as students. As a result the class attracted participation from people at many levels -- undergraduates, graduate students, post-docs, and faculty members. Students were required to write several short papers, which were usually revised and assembled into a final course document. The students usually did literature searches and worked on producing the final document. Graduate students and post docs explained basic concepts to the undergraduates. The faculty gave purpose to the enterprise by describing the historical context of the new ideas and explaining the significance of the current research.

3.2. Depth, Differentiation and Bureaucratic Coordination

Many Modes of Learning

The literature on learning styles suggests that some people learn primarily from reading, some primarily from listening, some primarily from working with their hands, and some primarily by working with other people. BCL used all modes of learning. There were people building various kinds of electronic devices, people doing mathematics, music composition and dance, and the usual academic work of lecturing and writing and publishing papers. As one example, the construction of the book *Cybernetics of Cybernetics* in 1974 employed all learning styles and the book itself makes possible the use of most learning styles. (Von Foerster, 1974)

Teachings on Several Levels

One feature of von Foerster's classes that made them much more interesting than the usual class is that they involved questions on several levels -- practice, theory, and philosophy. For example, machines built in BCL to demonstrate some aspect of perception, would inform theories of cognition, which would be used to question propositions in the philosophy of science. In the early 1970s Stafford Beer (1974) published *Platform for Change*, which uses different colored paper for explanations at different levels of analysis. After reading this book, von Foerster gave a lecture in which he used different colored cards hanging around his neck to indicate the level of analysis of the different parts of his lecture. The first author found it surprising how often he had to change the card that was visible.

As this description indicates, von Foerster's style of teaching was different in many ways from the usual required and elective courses. Occasionally people ask how he got away with offering such unusual courses. Occasionally he had to smooth some ruffled feathers among administrators, and once he was summoned to the state capital in Springfield, Illinois, to answer questions by legislators. But usually there were few problems. The courses were offered as "special projects courses." Students could receive either undergraduate or graduate credit. The courses were offered only one semester. Each semester there would be a new course on a new topic. Most universities in the US now have "special projects courses." But they are usually used to develop new courses for the catalogue rather than to conduct research by a group of faculty members and students.

Support and Encouragement for All Contributions

Von Foerster believed in the self-evaluation of learning. Students were invited to suggest the grade they should receive based on how much they felt they had learned in the course. All contributions, no matter how strange or unusual, were greeted with a smile and praise. Ideas were evaluated through a sense of play rather than whether they were "correct." Since all ideas revealed something about an observer and all observers were "legitimate," all ideas were part of an on-going conversation. Each expression of an idea was an opportunity to adjust the conversation to the needs of the participants. If some people needed background information, for example in a discipline other than their own, someone would meet with that person or persons after class. The purpose of the course was to invent new ideas or interpretations rather than to communicate accurately already accepted ideas. Furthermore, von Foerster maintained that there are two kinds of questions – legitimate questions and illegitimate questions. Legitimate questions are questions to which answers are NOT known. Illegitimate questions are questions to which the answers ARE known, for example the questions in textbooks. Von Foerster's classes were aimed at answering legitimate questions.

Transparent Information

As a student, one of the features of BCL that the first author most appreciated was how easy it was to find out what was going on there. The secret to information sharing was remarkably simple. In the front office where the receptionist's desk was, von Foerster had put a board on top of a radiator. On the board were small stacks of recent publications. From time to time while walking across campus, the first author would make a slight deviation from his usual path

and pass through the front office of BCL. He would look at the papers on the board on the radiator and take a copy of those that looked interesting. If there was something in a paper that he did not understand, he would ask someone for an explanation. There was always someone in the office who could answer or who could suggest a person who would be able to answer.

A Different Approach to Conferences

Von Foerster's approach to conferences was also quite different from the usual academic conference. Most academic conferences consist of carefully scheduled presentations of research results with a discussion following each presentation. Von Foerster's idea of a conference was more like a conversation among friends who do not often see each other. His presentations were intended to arouse interest, raise questions, and create doubts about current beliefs. He did this by presenting research results about perception or cognition, which challenged prevailing assumptions. The purpose of a conference was less to present the results of past research than to stimulate interest in new directions for future research. (Umpleby, 1987).

3.3 Cognitive Integration

Art and Analogical Reasoning

BCL was unique in the attention paid in a scientific research laboratory to the visual and performing arts. This orientation seemed to be the result of von Foerster's upbringing in the artistic community in Vienna between the two world wars. The effect of combining mathematics, science, and art was to stimulate analogical and metaphorical reasoning. By looking at examples in very different fields, students could appreciate the very general nature of the circular and self-referential phenomena being considered.

Social Activities

At least once or twice a year Heinz and Mai von Foerster would invite the "friends of BCL" to their home for an evening. These occasions, which were delightfully lively with von Foerster as master of ceremonies, were very helpful in promoting informal communication among the students and researchers in BCL. The office itself was also a place of activity, excitement, and friendliness with people engaged in tasks ranging from engineering to graphic arts and with blackboards filled with diagrams and mathematics.

3.4 A Large and Grand Vision

The goal of von Foerster's research was to include the observer in the scientific enterprise. This goal required a fundamental change in the philosophy of science. Although the appropriateness and reasonableness of the idea was readily apparent to anyone who had encountered cultural differences, most of the research at BCL approached the task through neurophysiology and mathematics. The work at BCL was aimed not at making an argument for a plausible idea but rather at constructing a scientific proof for the necessity of including the observer based on an improved understanding of the nature of cognition. Hence, the idea was to transform the philosophy of science, and assumptions about human relationships, by doing leading edge research in biophysics, engineering, and communications.

4 Conclusions

After BCL closed in 1975 conversations among the previous members of BCL continued both on-line (Umpleby, 1979, 1983) and at meetings of the Society for General Systems Research in the late 1970s and the American Society for Cybernetics in the 1980s and 1990s. As we learn more about how to effectively organize and support innovative research activities, how to collaborate among various types of organizations, and how to create innovative research teams, BCL will stand out as one of the paradigmatic examples of a highly innovative research group.

REFERENCES

- Amabile, T. M., Patterson, C., Mueller, J., Wojcik, T., Odomirok, P. W., Marsh, M., and Kramer, S. J. (2001), "Academic-practitioner collaboration in management research: A case of cross-profession collaboration," *Academy of Management Journal*, Apr., Vol. 44, No. 2, pp. 418-432.
- Anbari, F. T. (2003), "Six Sigma, Project Management, and Strategic Management of Technology," [CD], *Proceedings of Portland International Conference on Management of Engineering and Technology (PICMET '03)*, Portland State University, Portland, Oregon.
- Anbari, F. T., Khilkhanova, E. V., Romanova, M. V. and Umpleby, S. A. (2003), "Cultural differences in managing international projects," *Proceedings of PM Days '03* [CD], Vienna, Austria.
- Anbari, F.T., S. Umpleby (2005), "Productive Research Teams and Knowledge Generation", in: E.G. Carayannis, D. F.J. Campbell (2006)(eds.), *Knowledge Creation, Diffusion, and Use in Innovation Networks and Knowledge Clusters: A Comparative Systems Approach Across the United States, Europe, and Asia*. Westport: Greenwood Publishing Group, pp. 26 – 39.
- Beer, S. (1974), *Platform for Change*. New York, NY: Wiley.
- Biological Computer Laboratory. (n.d.) Retrieved 5/6/2004 from www.ece.uiuc.edu/pubs/cenhist/six/bcl.htm.
- Campbell, David F.J. (2003), "The Evaluation of University Research in the United Kingdom and the Netherlands, Germany and Austria," in Philip Shapira and Stefan Kuhlmann (eds.), *Learning from Science and Technology Policy Evaluation: Experiences from the United States and Europe*. Cheltenham: Edward Elgar, pp. 98-131.
- Carayannis, E. G., and Laget, P. (2004), "Transatlantic innovation infrastructure networks: Public-private, EU-US R&D partnerships," *R & D Management*, Oxford, Jan., Vol. 34, No. 1, pp. 17-32.
- Eppler, M. J. and Sukowski, O. (2000), "Managing team knowledge: Core processes, tools and enabling factors," *European Management Journal*, London, Jun., Vol. 18, No. 3, p. 334.
- Gilman, T. J. (2001), *No Miracles Here: Fighting Urban Decline in Japan and the United States*, Albany, NY: State University of New York Press, 208 pages.

- Greve, H. R. (2003), "A behavioral theory of R&D expenditures and innovations: Evidence from shipbuilding," *Academy of Management Journal*, Briarcliff Manor, Dec., Vol. 46, No. 6, p. 685.
- Hage, J. and Hollingsworth, J. R. (2000), "A strategy for the analysis of idea innovation networks and institutions," *Organization Studies*, Berlin: Vol. 21, No. 5, pp. 971-1005.
- Hagedoorn, J. and Cloudt, M. (2003), "Measuring innovative performance: Is there an advantage in using multiple indicators?" *Research Policy*, Sep., Amsterdam, Vol. 32, No. 8, p. 1365.
- Hayashi, T. (2003), "Effect of R&D programmes on the formation of university-industry-government networks: Comparative analysis of Japanese R&D programmes," *Research Policy*, Amsterdam, Sep., Vol. 32, No. 8, p. 1421.
- Heims, S. J. (1991), *The Cybernetics Group*. Cambridge, MA: MIT Press.
- Hollingsworth, J.R., E.J. Hollingsworth, J. Hage (2006), *Fostering Scientific Excellence: Organizations, Institutions, and Major Discoveries in Biomedical Science*. New York: Cambridge University Press.
- Hollingsworth, J.R., K.H. Müller, E.J. Hollingsworth (eds.)(2002), *Advancing Socio-Economics: An Institutional Perspective*. Lanham, MD: Rowman and Littlefield Publishers.
- Hollingsworth, J.R., R. Boyer (1997)(eds.), *Contemporary Capitalism: The Embeddedness of Institutions* New York: Cambridge University Press.
- Hollingsworth, J.R., P. Schmitter, W. Streeck (1994)(eds.), *Governing Capitalist Economies: Performance and Control of Economic Sectors* New York: Oxford University Press.
- Hollingsworth, J.R., E.J. Hollingsworth (2000), "Major Discoveries and Biomedical Research Organizations: Perspectives on Interdisciplinarity, Nurturing Leadership, and Integrated Structure and Cultures", in: P. Weingart, N. Stehr (eds.), *Practising Interdisciplinarity*. Toronto: University of Toronto Press, pp. 215-244.
- Knorr-Cetina, K. and Bruegger, U. (2001), "Transparency regimes and management by content in global organizations: The case of institutional currency trading," *Journal of Knowledge Management*, Kempston, Vol. 5, No. 2, pp. 180-195.
- Kuhlmann, S. (2001), "Future governance of innovation policy in Europe - three scenarios," *Research Policy*, Amsterdam, June, Vol. 30, No. 6, p. 953.
- Lester, D. H. (1998), "Critical success factors for new product development," *Research Technology Management*, Washington, DC, Jan. / Feb., Vol. 41, No. 1, pp. 36-44.
- Miotti, L. and Sachwald, F. (2003), "Co-operative R&D: Why and with whom? An integrated framework of analysis," *Research Policy*, Amsterdam: Sept., Vol. 32, No. 8, p. 1481.
- Morgan, C. P., Dailey, R. C., and Kulisch, W. A. (1976), "The Composition of Effectiveness and Ineffectiveness in R & D Project Teams," *Academy of Management Proceedings*, pp. 500-505.
- Müller, K.H. (2000), "Wie Neues entsteht", in: *Österreichische Zeitschrift für Geschichtswissenschaften* 1 (11), pp. 87 – 128.
- Pias, C. (ed.) (2003), *Cybernetics | Kybernetik. The Macy-Conferences 1946-1953, vol. 1. Transactions/Protokolle*. Zürich: Diaphanes.
- Pias, C. (2004), *Cybernetics | Kybernetik. The Macy-Conferences 1946-1953, vol. 2. Documents/Dokumente*. Zürich: Diaphanes.
- Shapira, P.(1997), "The Technological Reshaping of Metropolitan America," *Journal of the American Planning Association*, American Planning Association, Chicago, Winter, Vol. 63, No. 1, pp. 158-160.
- Shapira, P. (2002), Book Review: "No Miracles Here: Fighting Urban Decline in Japan and the United States," *Pacific Affairs*, Vancouver, Spring, Vol. 75, No. 1, pp. 119-121.
- Shapira, P. and Furukawa, R. (2003), *International Journal of Technology Management*, Geneva, Vol. 26, No. 2,3,4, p. 166.
- Sicotte, H., Prefontaine, L., and Ricard, L. (2004), "New product development: Customers' and suppliers' assessment of the same project," *International Journal of Technology Management*, Geneva, Vol. 27, No. 2, 3, p.176.
- Umpleby, S. A. (1987), "Three Conceptions of Conversation," *Continuing the Conversation*, Newsletter of the American Society for Cybernetics, No. 10, Fall, pp. 17-18.
- Umpleby, S. A. (1979), "Computer Conference on General Systems Theory: One Year's Experience," In M. M. Henderson and M. J. MacNaughton (eds.), *Electronic Communication: Technology and Impacts*. Boulder, CO: Westview Press, pp. 55-63.
- Umpleby, S. A. and Thomas, K. S. (1983), "Applying Systems Theory to the Conduct of Systems Research," In A. Debons (ed.), *Information Science in Action: System Design*. Vol. I, The Hague: Martinus Nijhoff, pp. 381-395.
- Vaill, P. B. (1982), "The Purposing of High-Performing Systems," *Organizational Dynamics*, New York, NY, Autumn, Vol. 11, No. 2, pp. 23-40.
- Von Foerster, H. (ed.) (1974), *Cybernetics of Cybernetics*, Minneapolis, MN: Future Systems.

Table 2. Von Foerster's Perspectives on Education in Context

**Traditional Assumptions
about Education**

Von Foerster's View of Education

The aim of education is to produce predictable citizens.

The purpose of education is to trivialize students. A trivial machine always produces the same output for a given input.

There is one right answer.

Example: What is 3×2 ?
Answer: 6.

To find out what students know, give them a test.

Tests test those being tested.

A good report card means a student has learned the material in the course.

The traditional view is that teachers know everything and students know nothing. The task of pedagogy is to transfer knowledge. Learning is the step by step elimination of ignorance.

The agenda for learning is set by the teacher.

Teachers feel they have superior knowledge.

The teacher is *supposed* to know.

The aim of education is to produce thinking, reflecting, responsible, creative citizens.

The purpose of education is to help the individual to develop by honoring his or her thoughts.

There is a whole range of possible answers. Detrivialization means pointing out other possible answers and encouraging people to come up with a variety of solutions and perspectives.

What is 3×2 ? Answers: 2×3 , the square root of 36, $5 + 1$, $8 - 2$, etc.

One can never know what students know, because they are non-trivial systems.

Tests test tests. Consider the Turing test. A group of scholars try to determine whether a thing behind a curtain is a human being or a machine by asking questions. If they think it is a human being, but the thing is a machine, then the machine is judged to be intelligent. But actually they are testing themselves. Hence, tests test tests.

A good report card is a sign of successful trivialization.

Knowledge cannot be transmitted. It is generated by people themselves. The key factor is providing conditions that allow generation and creation to take place. Learners are not passive. They are not empty containers to be filled with facts. Learners actively create their knowledge.

The task of teachers is to create opportunities for students to use and expand on the material they are exposed to.

Adopt the attitude of Socratic ignorance, "I know that I know nothing." If one knows that one does not know, do research.

The teacher is *eager* to know. Pupils and teachers become collaborators who create knowledge together starting from a question that is

fascinating to both of them. An atmosphere of cooperation, a common search – yes, research – comes about. Each person is dependent on the other person's skills and knowledge. The questions one is confronted with become one's own questions.

Students have nothing to teach teachers.

Students can make teachers aware of their idiosyncrasies, their biases and teach them how they have become accustomed to viewing the world.

Adapted from Heinz von Foerster and Bernhard Poerksen, *Understanding Systems: Conversations on Epistemology and Ethics*. Plenum Publishers, 2002.