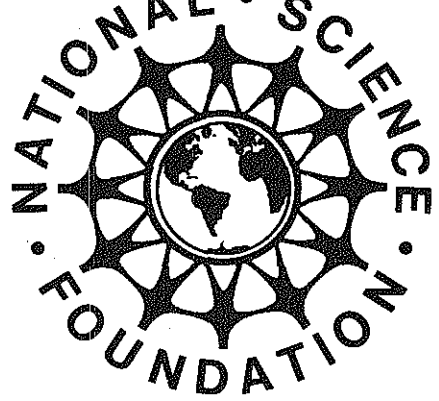
COOPERATIVE SCIENCE: A NATIONAL STUDY OF UNIVERSITY AND INDUSTRY RESEARCHERS

CASE STUDIES

PRODUCTIVITY IMPROVEMENT RESEARCH SECTION

DIVISION OF INDUSTRIAL SCIENCE & TECHNOLOGICAL INNOVATION



NATIONAL SCIENCE FOUNDATION

VOLUME II
NOVEMBER 1984

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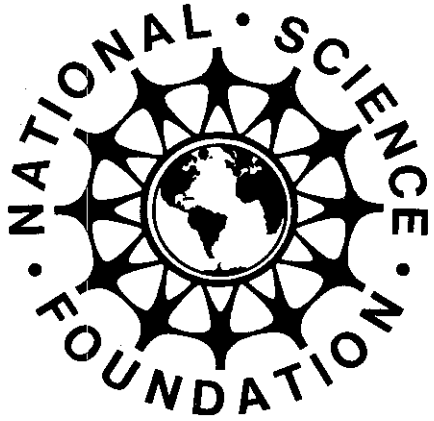
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by

Elmima C. Johnson
Louis G. Tornatzky
Lynne R. Schlaaff

Productivity Improvement Research Section

Any opinions, findings, and conclusions or recommendations expressed in this report are those of the authors and do not necessarily represent the views of the National Science Foundation.

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EXECUTIVE SUMMARY

It is difficult to capture the essence of the descriptive case material with a few well-chosen generalizations or "nuggets." These IUCR projects were complicated undertakings, and for many of the participants they represented significant milestones in their professional lives. Nonetheless, there appears to be at least one integrating concept to apply to the results.

The concept that might be employed is the *social network*. A social network is an organizational and sociological concept that has been used to describe the complex web of communication and interaction that characterizes most human groups. It has been used as an analytical tool to understand phenomena such as friendship cliques, bureaucratic organizations, and scientific specialities. The nine cases presented here confirm the importance of social networks in the prior relationships between the participants, the management of the projects, and the results achieved.

Prior Relations and Project Initiation

The development of these cooperative relationships was a slow and cumulative process. Research collaboration did not result from a single chance encounter, nor was it a product of an organized search for compatible technical expertise. Most if not all of these projects were preceded by extensive interpersonal contact, collaboration, mentorship, and, in some cases, friendship. There were several prior student-faculty relationships in these IUCR projects, as well as consulting relationships, sharing of papers, and the like.

For example, six of the nine projects involved prior consulting relationships between the university researcher and the collaborating firm. In another project, while there was no prior consulting relationship, this was simply because the firm did not even exist until it was created by a former university professor. In only one project was there no concrete prior relationship between the principals, although in that case they were aware of each other's work. There were other connecting links. Four of the projects involved industry researchers who were current or former students at the collaborating university. In one case a mentor/student relationship had extended from undergraduate days through the Ph.D. In two additional projects the industry investigators were former or current faculty at the university. Five projects involved co-investigators who had performed research and/or published together. One project had neighbors as collaborators.

For the most part, these were relationships between peers. Eight of the nine academic researchers were full professors and the industry investigators were primarily senior scientists in their organizations. Full-time cross-sector work experience (academics in industry and vice versa) was also comparable in seven of the projects, although this experience was generally negligible for both sets of participants. The organizations involved in these projects were also comparable in scope/size. Seven of the nine firms were Fortune 500 companies; and seven of the universities involved ranked in the top 100 in total R&D expenditures. These observations were generally consistent with the findings in the quantitative analysis of the 118 projects.[1]

Project Management/Coordination

Interaction during the course of the projects reflected the pattern that had developed prior to their initiation. In the terminology of interorganizational sociology, the industry and university scientists seemed to be quite adept at "boundary spanning" or reaching beyond their nominal institutional constraints. The course of each project depended heavily on ongoing intra-project communication. One comes away from reading these cases with a vision of exciting intellectual interchange that persisted over the course of many months. Frequent phone calls, meetings, and late night "bull sessions" all seemed to be important parts of these projects. While such communication patterns are probably characteristic of any successful research team, they were particularly crucial for these cooperative projects.

For the most part the university and industry co-investigators each managed autonomous sub-projects, which complemented the work being conducted by their collaborators. This relative independence exacerbated the need for coordination between the two efforts, and the richness of these communication linkages was considerable. In all of the projects save one, there was phone or face-to-face communication that was regular and informal. Despite the fact that physical distance was often considerable (ranging up to 3,000 miles apart) the ease with which the research communicated yielded an enhanced collaborative effort. These media linkages were extended by "embodied" knowledge transfer; in four of the projects there was personnel exchange between the university and industry sub-projects.

[1] Elmima C. Johnson and Louis G. Tornatzky, *Cooperative Science: A National Study of University and Industry Researchers* (Washington, D. C.: National Science Foundation, 1984).

Results of Cooperation

There were several tangible results from the cooperation. The nine cases produced at least three books, numerous articles, and a minimum of five MA/PhD theses. One PhD thesis was published as a book (the first time in the history of that department) which was enthusiastically received. One post-doctoral researcher developed an important experimental procedure, and credited the opportunity to work with an industry scientist and use sophisticated industry equipment as crucial elements in his success.

The nature of the science itself also seemed to change as a result of the IUCR experience. In two-thirds of the cases methodology and research foci were seen as changed as a function of the cooperative interaction. Participants seemed to have altered their epistemologies positively and significantly. The cases are replete with admissions by mature scientists of how their perspectives on their science had changed. In some sense the cooperative science practiced in IUCR may be a way of pressing the boundaries of what Kuhn called "normal science."[2] Indeed, one of the issues that might be addressed in subsequent work is the extent to which cooperative science alters the paradigm of the inquiry.

Personal outcomes varied. Overall the researchers saw increased prestige among colleagues and in the larger scientific community as the primary benefit. More tangible rewards, such as salary increases or promotions, were mentioned most frequently by industry scientists.

Two industry investigators were able to leverage knowledge gained through the project to secure better positions in other companies. Another researcher obtained a permanent position within his firm based on the IUCR project. One university researcher received an award based on his work.

Finally, it is worth commenting on the generally positive nature of the experience observed among IUCR investigators. While many participating scientists approached the cooperative venture with some misgiving, virtually all of them came away as enthusiastic advocates. While these kinds of outcomes are probably unrelated to more specific economic and technological outcomes, at least it appears that cooperative science will be a growing force in the American intellectual community.

There were minor criticisms about program management and a few related suggestions. Criticisms included the length ot the review process, uncertain funding, and the limited range of fundable topics. (Most of these have been resolved by subsequent changes in IUCR program policy.) The most significant suggestion for program expansion was to match university and industry scientists with similar research interests using vehicles such as workshops, industry sabbaticals, etc.

Highlights

Cooperative science between university and industry researchers is an incredibly complex logistical, interpersonal, and organizational undertaking and a comprehensive summary of these projects is difficult. However, the following statements highlight major trends in the case analysis:

- There had been extensive interpersonal contact between university and industry scientists prior to the IUCR projects including collaboration, student/faculty relationships and in some cases friendships.
- The co-investigators were, for the most part, academic and experiential peers in their respective fields. Their organizations were also comparable in scope/size.
- Full-time cross-sector work experience was comparable, though negligible for both sets of researchers.
- Intra-project communication and coordination was frequent and generally informal. It transcended organizational boundaries and distance.
- Although approximately one-half of the projects were still in progress, the researchers anticipated a variety of intellectual products including books, articles, etc.
- Changes in the nature of the science (i.e., in research methods and topics), were reported in two-thirds of the projects.
- Increased prestige was the primary personal benefit emphasized by both sets of researchers. More tangible benefits (salary, promotion) were anticipated primarily by the industry researchers.
- Both university and industrial participants expressed a high degree of general satisfaction with the IUCR project, including technical quality of the research, communication patterns, and project administration.
- Participants suggested that NSF play a more active role in matching university and industry scientists with similar research interests.

[2] Thomas S. Kuhn, *The Structure of Scientific Revolutions*, International Encyclopedia of Unified Science (2nd ed.; Chicago: University of Chicago Press, 1970), pp. 10-22.

Chapter 1

OVERVIEW OF THE STUDY

Introduction

This report presents nine case studies of Industry/University Cooperative Research (IUCR) projects supported during 1978-1980 by the National Science Foundation's Division of Industrial Science & Technological Innovation. The intent is to provide readers with a qualitative picture of cooperative science as practiced under the IUCR program. The information presented here is illustrative and hypothesis-generating rather than definitive or hypothesis-testing. We describe ongoing processes, rather than make causal inferences or quantitatively-based generalizations.

Cooperative research in the IUCR model is probably not the norm in American science. To have two or more investigators, separated by distance and institutional affiliation, combine their efforts into a common intellectual product is a difficult undertaking indeed. Moreover, the separation between university and industry scientists in this country has historically been epistemological as well as geographic. Universities in the U.S. have been the home of basic research; American industry has been primarily concerned with applied research and development.

The IUCR program represents one attempt to bridge these gaps. The program sponsors research projects in the physical and biological sciences and in engineering performed *jointly* by university and industrial scientists. Projects focus on fundamental science, but are also expected to be relevant to industrial operations and technology development. Since the inception of the program in 1977 over 250 projects have been funded. Each of these projects represents an interesting story in both the advance of science, and in the organization and management of a logistically complex intellectual task. The case studies presented here are a small sample of those experiences.

This report will present data which hopefully can enhance our practical understanding of industry-university collaboration, and also add to the scholarly literature on innovation processes and organizational behavior.

Relation to Other Assessment Activities

This study is one component of a three-part assessment of the IUCR Projects Program undertaken by the Productivity Improvement Research Section at NSF. The first phase of that assessment began in 1981 and consisted of a descriptive analysis of 118 grants awarded in FY 78-80, the first three years of program operations. Information on grants, participants and their organizations was obtained from archival sources, primarily grant files. The study was completed in April, 1982.[3] The second part of the assessment was a mail survey of the 236 university and industry researchers involved in the 118 projects identified in the first phase. The purpose was to determine the nature of the role relations and transactions involved in the typical IUCR project, and results and benefits achieved by both industry and university participants. The results of this survey are summarized in a companion volume.[4] As the third phase of the assessment effort, nine of the 118 projects were selected for case study analysis. The purpose was to chronicle the implementation of the projects, highlighting participant views of this collaborative research venture, and its impact on them and their institutions. That effort is described in this volume.

Issues and Questions

While much has been made of the importance of knowledge transfer and dissemination in the innovation process,[5] there have been few organized attempts to influence that process on a large scale. The IUCR program is one of a very few Federal efforts to develop explicit bridges between the world of academia and the world of commerce. A major premise of the program is that university basic science can be more attuned to industrial interests without sacrificing its essential character, and correspondingly that industrial science can be enriched by linkage to theoretically-driven research. The issue, of course, is how to facilitate this reciprocal knowledge transfer between university and industry organizations.

The IUCR program attempts to institutionalize such interorganizational interaction through the funding mechanism itself. Within the short history of the program there have been both recurrent themes and con-

[3] Elmima C. Johnson, Louis G. Tornatzky, Patti Witte, and Claire Felbinger, *Assessment of the Industry/University Cooperative Research Program (IUCR): Interim Report 1. Descriptive Analysis of Projects FY 1978-1980* (Washington, D. C.: National Science Foundation, 1982).

[4] Elmima C. Johnson and Louis G. Tornatzky, *Cooperative Science: A National Study of Industry and University Researchers.* Assessment of the Industry/University Cooperative Research Projects Program (IUCR), (Washington, D. C.: National Science Foundation, 1984).

[5] Louis G. Tornatzky, J. D. Eveland, Myles G. Boylan, William A. Hetzner, Elmima C. Johnson, David Roitman, and Janet Schneider, *The Process of Technological Innovation: Reviewing the Literature* (Washington, D. C.: National Science Foundation, 1983), pp. 155-175.

siderable variability in how IUCR projects evolve, and in the nature of outcomes achieved. The purpose of this study, and of the entire three-part assessment effort, has been to describe how IUCR projects usually developed, and, if possible, to discover what project features contributed to successful technical and organizational outcomes.

In designing the assessment studies, it became abundantly clear that university/industry research interaction is not an area that has received much empirical attention. A review of the literature indicated that there were some useful concepts that could be borrowed from organizational sociology, but few firm findings.[6] As a result, the selection of variables and variable domains for the studies was less focused than it might have been in a more mature area of inquiry. Nonetheless, there were several sets of factors which seemed useful to examine.

For one, we were interested in the *demographics* of participants. What kind of scientists, from what kind of institutions, become involved in cooperative projects? Were they "outliers" or well-known investigators? Were the companies small entrepreneurial enterprises or large companies?

A related issue concerned the *prior history* of interaction between participants. Could it be assumed that the IUCR program itself fostered research interaction between former strangers, or rather that it served as a catalyst after a long prior history of other kinds of exchange? To what extent were IUCR collaborating scientists involved in friendship or collegial networks with each other prior to a project? Similarly, what was the "track record" of cross-sector interactions between the participating institutions?

We were concerned not only about the general history of prior interactions, but also about the specific events that led to the *initiation* of an IUCR project. How did the principals hear about the program? What role did NSF staff play? Would the project have been implemented or even considered in the absence of an IUCR program? Who took the initiative in constructing the research project and proposal?

We were also interested in the *management* of these projects. How did separation in affiliation and geography affect project management, group dynamics, communication patterns, and the like? A particularly important aspect of this line of inquiry was how the two sets of investigators—university and industry—coordinated their activities and divided their responsibilities. How does a geographically and organizationally decentralized project work?

Finally, we were interested in the *outcomes* of IUCR projects—not only intellectual and technical outcomes, but possible commercial results. To what extent could we expect new products or processes to be generated by the cooperating company? What contributions to general science might result? Within the general category of effects was the question of how participation changed the participants themselves. Did university scientists become more aware of industrial needs and operations, and vice versa? Did scientists and students alter their career directions?

These and other questions have guided the data collection in this study, and in the accompanying national survey. Again, our intent in presenting these cases is to capture in a descriptive fashion the nature of cooperative science practiced in the IUCR program.

Methods and Procedures

Selection of Projects

There was no attempt at random selection of projects representative of the entire population; projects were selected in order to maximize variability along certain dimensions including firm size, public versus private universities, and distance between the cooperating investigators. Also included was one project which was selected by the IUCR Program Manager as exemplary in terms of quality of the research, results, and the level of industry participation. In all, nine projects were selected.

Data Collection

The two interviewers, members of the PIR staff, were briefed by the program managers on the technical aspects of each project prior to the site visits. In addition, each program manager contacted his grantees to alert them to the purpose of the visit and to elicit their cooperation. Researchers were informed that their participation was voluntary, that this visit was not a program review and would not influence future funding decisions. The projects were in various stages of operation at the time of the site visits and several were in the process of applying for renewals. All had been in operation at least one year. The site visits occurred in August-September 1982, and included a review of responses to the questionnaire that was used in the national survey, as well as an indepth discussion of research relationships and the impact of the project on the collaborating organizations. Other project team members and organization officials were interviewed when available. All interviews were tape recorded and transcribed.

The strategy of the case study data collection was straightforward: encourage our respondents to elaborate in a more open-ended context the answers given

[6] Elmima C. Johnson and Louis G. Tornatzky, "Academia and Industrial Innovation," in *New Directions for Experiential Learning: Business and Higher Education—Toward New Alliances*, ed. by G. Gold (San Francisco, California: Jossey-Bass, 1981), pp. 50-53.

to the structured instrument used in the companion survey. In addition, an attempt was made to obtain convergent data by talking to other personnel at the sites, to observe interaction, to review documents, and to get an experiential "feel" for each project.

Analysis and Case Format

The cases presented here have been distilled from over 1,000 pages of transcripts and written responses to a lengthy questionnaire. Each transcript and set of questionnaire responses was organized into the following categories: 1) project and participants; 2) prior cross-sector collaboration; 3) initiation of the collaborative project; 4) project management and decision making; 5) coordination; and 6) benefits and outcomes. This format was used in each case report and was developed to highlight similarities as well as differences in project activities.

We have attempted to capture the flavor of the interactions as well as to present factual information concerning project logistics. Extensive use of direct quotation has been made. Since some of the researchers requested anonymity, we have disguised the identity of all of the projects. Obviously this was difficult to accomplish in some cases and required that we limit our discussion of the technical nature of the research. Each case study was reviewed by the respondents for accuracy and propriety, and was approved for publication. However, primary authorship of these cases rests with PIR staff.

The cases are presented as nine separate chapters. No particular ordering of the cases is intended. Each of the case chapters should be considered as both a unique combination of researchers and areas of science, and also one of a set of stories with general and recurring themes.

Chapter 2

A PROJECT ON COMPUTER LANGUAGE SYSTEMS

Overview of Project and Participants

The focus of this project was computer language systems, in particular the conversion of language systems used by programmers into machine languages used by the computers themselves. The participating firm was a Fortune 500 electronics company; the participating university was a major land grant university in the midwest. The university principal investigator was an electrical engineer; the industry principal investigator was a computer scientist. The university researcher was in his mid-40's, and had spent his entire academic career at this university, with a brief tour of one year in industry. His department was not at the time among the top ten in the field, although this particular researcher had been quite professionally active, received several grants, and had published extensively.

The industry researcher, in contrast, had spent nearly a decade in the electronics industry. Virtually all of his time had been in a research and development capacity. During the period of the IUCR grant, the industry researcher was working towards his Ph.D. degree, and in fact the IUCR project was a major portion of his dissertation. Despite his student status, the industry researcher remained a part-time employee of his firm, and worked full-time there during the summer months. After the termination of the IUCR grant, the industry participant changed companies, leveraging research skills and knowledge acquired during the project into a more responsible position.

The project itself was supported by 2 two-year grants from the NSF funded consecutively. No funds were given to the industry participant.

Prior Cross-Sector Collaboration

Prior University Activities. The faculty member involved in this project had extensive ongoing relationships with industry, and with the participating company in particular. He had contract research projects with industry for 10 to 12 years, as well as individual consulting relationships with several firms, including two in western Europe. The faculty member had also successfully placed students in industrial settings as part of their training.

The professor had a lengthy consulting arrangement with the company involved in the IUCR project. In the context of this consulting relationship, his work became known to a mid-level scientist in the firm, who eventually became the industry co-investigator on the project.

Prior Firm Activities. Prior to the initiation of this IUCR project, the participating firm had collaborative research and consulting relationships with university faculty from a variety of institutions. The industry scientist's situation was somewhat unusual in that he was part of both the university and the firm. He had left his company to pursue a Ph.D. program which was intimately tied to the IUCR project that evolved, and during the four calendar years that he spent at the university he was still on his company's payroll as a part-time employee, and had continued access to lab and computer facilities. The two investigators had never actually met prior to the industry scientist's returning to the university.

Initiation of the Collaborative Project

Preliminary Discussions/Work. Prior to the awarding of the NSF grant the university professor and the industry scientist had already made tentative plans to implement a project in the research area. The firm researcher had initially discussed a prospective project with the R&D managers at his firm, and had received essentially a negative response. A subsequent query to a product group within the company received a more sympathetic response, to the extent that the possibility of an in-kind contribution of personnel and computer time became a possibility. To a significant degree the conceptualization of the research project was underway before both the university and industry scientists became aware of the NSF program. The NSF program became the catalyst to successfully implement their plans.

Role of NSF IUCR Program. During these preliminary discussions the university researcher became aware of NSF's IUCR program. The university office of extramural research periodically circulated a flyer on new funding sources and programs, and the university professor read an issue in which the IUCR program was spotlighted. He contacted the industry researcher/graduate student, and the two of them decided that it would be worthwhile to write a proposal.

Both the university and the industry researchers felt that a project would not have been implemented, at least of the same scope, without the IUCR program. The industry researcher felt that some project might have been undertaken, but it would have been much more narrowly focused, and probably would not have contributed to the larger scientific literature. More emphatically, the university professor felt that the proj-

ect would not have been undertaken at all in the absence of the NSF grant. The academic norms at the time would not have been supportive, and he might never have thought of approaching industry with this type of research project. In addition, the nature of the work done could not have been accomplished without access to some of the sophisticated research equipment available in the industrial firm. The IUCR program enabled the researchers to move beyond mere short-term development issues, into more theoretically-driven issues of relevance to the larger scientific community.

Application Process and Internal Negotiations. Once the project proposal had been written, it was treated in a fairly straightforward manner in both the university and industry setting. An understanding was reached regarding use of underutilized computer facilities, in-kind contributions had been agreed upon, and the actual processing of the grant proposal was routine.

Project Management and Decision-Making

Project Structure. As were some of the other projects described in this volume, this project was an organizationally and logistically complex effort. There were three active research teams operating concurrently, at two geographically separated sites, working under the supervision of two different research supervisors. Complicating the management issues was the fact that one of the researchers was a graduate student and the other was a tenured professor. Personnel involved in the various sub-projects included undergraduate students, graduate students, and full-time professional engineers.

Specifically, the university professor supervised two masters level students on one sub-project, whose work comprised their master's theses. A second sub-project conducted at the university was supervised by the firm principal investigator/graduate student, and was staffed by five undergraduate students working part-time. The third sub-project was conducted at the firm itself, was supervised by the firm principal investigator from the university, and was staffed by two master's level engineers who were permanent employees of the firm. This team was supervised largely by "remote control" via letter and telephone. To a significant degree the three sub-projects operated autonomously. The university professor had very little to do with the supervision of the firm-based team or of the undergraduate team, and vice versa.

Management Style. The managerial style adopted by the university and firm researchers in their areas of project responsibilities differed considerably. For example, the university professor was heavily involved in problem definition and identification of research issues, establishment of the administrative structure of the project, personnel and selection of equipment. However, he was not extensively involved in bench level science, and the actual collection and analysis of data. This approach was partly a function of the professor's personal style, and more directly influenced by the fact that the sub-project under his direction was staffed by students doing their master's thesis. The thesis experience demanded a certain amount of self-direction for the involved students.

Management of the five undergradudate students by the industry researcher took quite a different approach. The industry co-investigator adopted a very directive and structured approach with the undergraduate employees. His view was that these individuals were relatively unsophisticated in terms of the science involved, and needed explicit direction and close supervision. One vignette is worth noting. Since the work conducted by these undergraduates was part of the firm researcher's dissertation project he needed to defend the scope and management of the work to his dissertation committee. There was considerable skepticism expressed by a professor on the committee about whether the work could be done in the nine months that the firm co-investigator had allocated for these activities. This committee member estimated that the work would take upwards of two and a half years to accomplish. There was some sheepishness and surprise on the part of faculty when in fact the firm researcher was able to motivate his team of undergraduate workers and make the deadline.

Interestingly, the management style adopted by the industry researcher with his team at the home firm was considerably different, and indicated a high degree of flexibility on his part. The personnel there were his educational and professional peers. In addition, the unit in which these two engineers worked tended to be operated in a collegial manner, and the supervisor relationship between the firm co-investigator and these two staff was of that nature. There was no perceived need to spell out in explicit detail the research tasks to be performed, or to provide close supervision of activity. As a result, a "hands-off" supervisory style was successful despite the fact that the work was done several hundred miles away from the university.

Coordination

Coordination Within the Project. Given the existence of three sub-projects, plus the geographic dispersion of the overall project, there was an obvious need for close coordination and communication between the two principal investigators. There were several factors that facilitated this necessary interaction. For one, the two co-investigators had offices on adjacent floors at the university. Several times a week they would meet face-to-face, and talk about activities of their respective teams. The student-professor relationship

also contributed to coordination. The university professor was the firm scientist's dissertation advisor, and the performance of the advisory function provided many settings in which coordination and communication could take place. Although the university and industry researchers were co-investigators on the grant proposal, and were thus presumably equals, one was clearerly more equal than the other. As the firm researcher pointed out, "as a thesis student . . . one is very careful." This is not to discount the fact that the faculty-student relationship was not a traditional one, and over the course of the project a great deal of mutual respect developed between the two researchers.

The firm researcher took upon himself much of the coordination between the various sub-projects. For example, most of the contacts with the researchers at the firm site were made by him, although the university researcher did make one or two site visits to the firm. After the industry scientist returned to the firm, during a latter period in the project, he continued his coordination efforts. Over a two-year period he made several return visits to the university, about once every two or three months. Some of these visits were not paid for by grant funds, but were made in the context of personal or other business trips to the metropolitan area in which the university was located. These coordination meetings were of course supplemented by frequent telephone contact, exchange of written documents, and some use of electronic mail.

There was also some intraproject communication that was facilitated by exchange and placement of students. During an early part of the project an undergraduate student spent a summer internship at the participating firm; during a latter part of the project a masters level student worked at the firm for a summer in the research lab. Another type of educational knowledge exchange occurred when one of the engineers at the firm spent two weeks studying under the university researcher, to better understand some of the more theoretical aspects of the work. This was in effect on-the-job training for the engineer, to enable him to better perform his functions on the ongoing project. This exchange was undertaken after the industry researcher had returned to his home firm, and decided it would be useful to send his colleague directly to the university professor or, in his words, to "the horse's mouth." It should be noted that not only did this engineer receive information from the university professor, but during his brief stay he was able to provide valuable feedback to the graduate students at the university who also were working on the project.

Coordination and Reporting External to the Project. In addition to communication among members of the project team, there was also some limited degree of communication with other individuals in the firm and university. For the university principal investigator there were no formal requirements for ongoing briefings or reporting of project activities. However, the university researcher did have his expected obligations to publish and contribute to the scientific literature. In addition, the university researcher kept one of the associate deans in his college well apprised of the project, and there was some ongoing interest from researchers in another academic department who were pursuing similar research interests.

As far as the firm researcher was concerned, he periodically informed the staff in the central R&D and production units about the project's progress. In particular, there was one individual in central R&D who was working on a similar project, and who was involved in a fairly constant dialogue with the firm co-investigator.

Benefits and Outcomes

Technical Outcomes. This research project generated various intellectual products. These included one book, two articles, and various internal reports and technical documents. Important to the university participants were the two masters theses, and the one Ph.D. dissertation that resulted directly from the project.

It should be noted that the book that resulted from this project was written by the industry participant, and constituted his doctoral dissertation. This was the only dissertation in the history of the department that had ever been published as a book, and moreover it achieved significant sales.

From the perspective of both university and industry researchers these tangible products were merely the visible evidence of a much more intangible increment in scientific knowledge. Both researchers felt that the work contributed significantly to basic understanding of the processes being investigated. The industry participant felt that the project expanded knowledge of the technical area and enhanced the quality of industrial and university research.

Knowledge Utilization. One manifestation of technology transfer is the exchange and dissemination of knowledge emanating from the project. The university investigator received some requests for information from within the university, but there were more frequent requests from external users. Within the university a group of researchers in the computer sciences department were investigating similar issues and were interested in the results of the project as they came out. Similarly, the university and firm researchers received requests for reprints and results, primarily from researchers in other universities. In contrast, the industry researcher received few requests from within his company, primarily from two sources. As in the case of the university, these internal users were pursuing lines of work compatible with that pursued in the IUCR project.

Aside from these more tangible instances of knowledge utilization, there is also the issue of the extent to which the project influenced the research agenda of the participant organizations. One possible type of influence would be a greater legitimation and higher priority given to this type of work in both the industry and university setting. Another type of outcome would be a more specific utilization of the findings as a lead in subsequent research.

There were changes in research priorities and follow-on work resulting from the project; however, the extent to which this occurred was probably less than optimal. On the university side, the project seemed to yield some grudging acknowledgement by the professor's colleagues that this type of industry-relevant work might be worth doing. This conclusion was abundantly clear for the university participant himself, who came to realize that working with industrial people brought problems to his notice that might have been ignored. In commenting on the limitations of traditional academic work, the university researcher pointed out the following:

> You tend to get the idea that once some solution has been shown to exist, the problem is finished, whereas it is a long hard road between the solution as perceived to exist and the technology in place to serve humanity in some sense.

The problems of applying the results of the research in industry were quite complex. It should be recalled that the industry researcher did not come from the R&D group within the company, but rather was affiliated with a product group. As a result, the regular research group within the firm was relatively uninterested in the work and had only "signed-off" on the project because it did not affect their own funding.

The NSF project did stimulate follow-on work in the firm but not with active support of the main line R&D unit. One project was taken in another non-R&D division, and a second project was only undertaken with further NSF money. The industry researcher felt that the project had caused some changes in research methods and procedures used in the participating company, and would almost certainly improve future projects, plus ultimately yielding commercial products.

However, more of these benefits will likely be realized in another firm. Although the industry researcher was eventually given a position in the R&D group, he was never given sufficient resources or a clear mandate to pursue the line of work undertaken under the NSF grant. As a result, he felt personally and professionally frustrated and moved to a larger electronics company. In this new setting he is extending the research conducted in the IUCR project. It is noteworthy that in his new company the industry researcher is again talking to his university-based collaborator about possible joint work, with or without NSF funding. In a sense, the research priorities of an industrial company have been significantly altered, but not the company that originally participated in the work.

The university researcher echoed this disappointment regarding technology transfer and implementation in the original participating company. In his view, the issue of technology transfer was the biggest negative aspect of the project, and he noted that the shortsighted posture of the company seemed to be the major problem. In his view, the industrial participants tend to get "jerked about" by a company's short term priorities. In his words:

> It's hard to keep an industrial person on a project like this for a long time because the company doesn't see it as something that is primary to their business of making money. If there is a fire some place they grab the guys that you've got working in the project and say "sorry, forget that."

It should be noted that the university researcher is still working with the orignal host company, and has some hope that the knowledge use situation may improve.

Personal Outcomes. Both university and industry researchers viewed their participation in the project as a professional growth experience. The university researcher felt that the industrial participation provided a strong reality check for his academic research. In his words:

> What makes me continue to do this university-industry business is that if you do something in the university you tend to get a kind of an academic flavor to it, which causes you to overlook problems that will exist in industry. The ability to have a check—to have somebody out there saying this is a bunch of bologna—I find that useful.

For the industry researcher, the NSF grant "opened doors" and enabled him to secure company resources which would have been difficult to obtain otherwise. He received much more in the way of tangible rewards for participation in the project than did the university professor. For the industry researcher, participation in the project positively affected promotion, salary, and visibility among his professional peers in industry.

A more indirect personal outcome was the job placement experience of one of the undergraduate students on the project. Apparently this individual was quite talented, had performed well on the project, and the participating company made a fairly generous offer (which the student rejected). The student was subsequently hired by another major company in the electronics industry.

Policy Issues

A major theme expressed by both university and industry researchers was the catalytic function of the

IUCR grant. The NSF program was seen as providing a rather unique incentive and structure for encouraging university/industry research relationships. Correspondingly, many of their suggestions for program changes or experimentation emphasized this catalytic and incentive function.

For example, one suggestion was that cost-sharing by industry ought to be a cash contribution rather than an in-kind contribution of staff or resources. The industry researcher felt this would enhance the likelihood of the research being used in his own company.

The university researcher also emphasized the catalytic function of the NSF in promoting university/industry cooperative research. In fact, he recommended that the NSF decrease its role as a granting agency and increase its role as a broker of cooperative research. For example, he suggested that the Federal government try to match university and industry performers who have similar research interests.

Neither the university nor industry investigator felt that a program such as IUCR would result in research being excessively applied in nature. They felt that the internal incentives structure of the university would preclude this, and that university researchers would only become involved in projects which allowed them to publish in the open scientific literature.

One common theme was the perceived importance of the government in providing a general milieu for this type of collaborative work. Although the specific mechanisms involved were unclear to the respondents, they felt that various policy levers (e.g., tax policy) might provide a viable device. Although neither the university nor industry researcher felt that the grant application procedure was particular onorous, they both felt that cooperative research could also be performed in the absence of grants. Whether they would have felt this way if they had not participated in an NSF supported cooperative project is unclear.

Both the university and industry researchers felt that the IUCR project was a way of "leveraging" scarce resources. For the university researcher it was a way of receiving industrial feedback to sharpen the academic research agenda. For the industry participants IUCR served as a vehicle to support basic research that might have long range industrial implications, without necessarily gearing up an entire laboratory effort to perform this task. As the firm researcher put it:

> Even though our two goals were different, . . . they meshed so perfectly that you couldn't have planned it any better. And I think there are many of these sorts of situations out there where two different goals, two different groups of people, can be brought together and realize that they complement one another.

Chapter 3

A PROJECT ON FLUID DYNAMICS

Overview of Project and Participants

This project was in the general area of fluid dynamics, with a particular emphasis on drag theory and the design of aerospace vehicles. The participating firm was a large aerospace company; the participating university was a major technological university in the south. The university principal investigator was in his late 40's, and had been trained as a mechanical engineer, receiving both bachelor's and Ph.D. degrees in that field. His current academic appointment was in a department of aerospace engineering. He had spent six years working in the aerospace industry following his Ph.D., advancing to the position of research manager, but had been in the university for over seventeen years. The university professor had published widely, was well-known in his field, and had received several awards. His department was considered among the highest rated in the field.

The industry scientist was also in his late 40's, and had a Ph.D. in aerodynamics. He had spent over a decade working with his present company, although prior to that he had spent a few years in a government research laboratory. The man was a staff scientist in his company, and supervised a small group of researchers. The industry scientist had very little direct experience working in a university context, though he had worked for brief periods with universities on a number of occasions.

The project was supported by a two-year IUCR grant. The work was to include theoretical development at the university site, and experimental work in the company research facilities. Both the university and the participating firm were located in the same state, and there was very little geographic hindrance to maintaining contact between the two parties.

Prior Cross-Sector Collaboration

Prior University Activities. The university researcher had some consulting relationships with large companies in the aerospace industry, including the firm involved in this IUCR project. In addition, the university had placed students in the aerospace industry, and participated in contract research projects with companies in the field.

Prior Firm Activities. The participating firm had a long history of working with universities. These included consulting relationships, contract research projects, and the placement of students. Pertaining to the latter, the industry researcher had participated as a member of a Ph.D. dissertation committee with another university. The participating firm also had some prior contact with another university in the particular research area that was studied in this IUCR project. Apparently the industry researcher had a friend who was a professor at a Canadian university, who had brought to his attention new results in this research area in the 1970's. The already-existing consulting relationship with the university professor proved to be quite compatible with the proposed research.

Initiation of the Collaborative Project

Preliminary Discussions/Work. As noted above, there was some prior discussion about this research area with both the Canadian professor and the professor who actually became involved in the IUCR project. The university and industry scientists worked together in the development of a paper on the research area, the content of which overlapped with their proposal to the NSF. This research area was not the primary activity being pursued by the university scientist at the time, but the existence of a prior consulting relationship enabled the firm and university researchers to rapidly focus their work on this promising new line of research. Much of the initial impetus for the project came from the industry scientist. He asked for some theoretical help from the university professor, which eventually evolved into the working relationship of the IUCR project.

Role of NSF IUCR Program. Both the university and the firm became aware of the IUCR program at about the same time. The university's office of research and development had circulated the IUCR brochure among various departments; the industry scientist learned about the program from one of his associates in the company.

Both the university and industry scientist felt it unlikely that the project would have been initiated in the absence of NSF support. Ironically, the industry scientist felt that internal support would have been difficult, not because of the inapplicability of the project, but because it was so broadly applicable across a number of areas that it would be difficult to get specific justification. In his view, the value of the NSF award was that it enabled "an injection of money at a point where the program was becoming difficult to sustain within the company."

The nature of the NSF IUCR grant also enabled the two researchers to perform compatible research func-

tions. Much of the theoretical/conceptual work was handled by the university scientist on the campus; most of the empirical and experimental work was conducted at the industry setting, using the extensive wind-tunnel facilities of the company.

Application Process and Internal Negotiations. Once the university and industry scientist had agreed to pursue this line of work, the actual writing of the proposal was fairly straightforward. On the university side the processing and sign off procedures for the proposal were also routine. The university had a fairly lengthy history of involvement with both the NSF and this particular company.

There were some logistical difficulties in processing the grant application as far as the firm was concerned. These difficulties centered around the IUCR program requirements regarding cost-sharing and in-kind contribution of resources. Since such arrangements were not commonplace at this particular company, the industry scientist had to engage in internal politicking to secure the necessary approvals.

Project Management and Decision-Making

Project Structure. The university scientist described the project as "two separate teams joined at the head." This tongue-in-cheek description is particularly apt. Virtually all of the empirical/experimental work was done at the firm wind tunnel; virtually all the conceptual/theoretical work was done at the university site. Thus, two quite different but clearly compatible subprojects proceeded in parallel in two different settings.

Staffing at the industry site included no more than four individuals in addition to the industry principal at any one time. These individuals consisted of members of the industry scientist technical staff, although there was some participation from other parts of the company. Staffing of the university-based team included the university professor, two graduate students, and one post-doctoral scientist who was used during the end of the project. Contact between the two sub-projects was exclusively through the two co-investigators. Although there was some contact between the two graduate students at the university, and with the staff at the participating firm, the actual task assignments and work supervision were handled by the principal investigators at each of the particular sites.

Management Style. The management style adopted by the university scientist was fairly directive with his team. As he saw it the research design was formulated by the principal investigators, task assignments were made by them, and members of the team merely carried out their assigned duties. The university scientist saw as his primary responsibility making sure that the research was performed, and supervising and coordinating the work of team members. Compared to the work conducted at the firm site, the activities undertaken by the university-based team were much more theoretical and conceptual. These included identification of the research area, problem definition, statement of hypothesis, analyses, and report writing.

The industry scientist's management style was much more collegial and informal. He took great pains not to be labeled as a "manager" by his team members. In his words:

> Now, as a scientist which I still regard myself as one, I cannot afford to become . . . tainted as a manager . . . . I try very hard to preserve the scientist image which is why I am dressed the way I am and I'm not wearing a tie and vest.

Congruent with this perspective, there was considerably more use of team discussion and the industry scientist saw his primary managerial function as coordinating and evaluating the work of team members. In order to accomplish the intellectual task of the project, he saw his major functions being to encourage sound thinking by team members, to encourage team members to evaluate ideas, and of course to evaluate the ideas of team members.

Coordination

Coordination Within the Project. There was considerable interaction between team members associated with the two subprojects which was facilitated by the geographical propinquity of the two sites. Although one project was primarily theoretical, and the other project primarily experimental, there was a constant use of each subproject's results in the other subproject's activities. There were many lengthy phone calls between the two co-investigators as well as several meetings per year in which team members from the two subprojects interacted. Thus although the daily operations of the subprojects were quite independent of one another, the cross-fertilization of ideas and results was extensive. As described by the university principal:

> We have more phone conversations than face-to-face meetings. But, they are just about equally important now. Because there are a lot of questions that you can't resolve by phone. You have to sit down and with a pad in front of you, with a lot of paper in front of you, you know, to work it out.

Most of the face-to-face liaison meetings took place at the university, and there was no clear pattern in terms of who initiated the interactions. Overall coordination was helped by direct personnel transfer between the two subprojects. Some of the staff at the industry site were former students of the university professor. In addition a post-doctoral scientist was placed at the firm through the auspices of the university scientist.

Little of the coordination involved "joint management" in the true sense of that term. Theoretical work was largely done at the university; the experimental

work was situated at the industry site. There was some overlapping activity in the analysis of data which accounted for only about a quarter of total project activity.

In summary, inter-project coordination was facilitated in this research by the physical proximity of the two subprojects. The nature of interaction tended to be frequent, informal, and involving either face-to-face meetings or phone conversations. Although there was a fairly strict segregation of different parts of the projects between the two sites (experimental versus theoretical) there was extensive cross-fertilization of ideas and results.

Coordination and Reporting External to the Project. The industry researcher was under some fairly strenuous reporting obligations. Every three months he had to make a formal presentation on the project to an internal committee. This presentation was concerned more with schedule and finances rather than technical detail. The company's R&D management was aware of general progress of the project, but did not follow the project closely.

In addition to formal reporting requirements, there were requests for information about the project from both within and outside the company. One paper was presented at a professional society, and the industry principal investigator was asked to repeat his presentation at a major aeronautical company. Several dozen reprints of this presentation were sent to people within the company and elsewhere.

In a corresponding manner, there were more requests from outside the university than from within the university for reprints from the university scientist. In addition, the university researcher was obliged to keep his office of contract administration apprised of the progress of the project.

Benefits and Outcomes

Technical Outcomes. Two written reports were generated by the project, one a final report and the second a paper presented to a professional society. In addition, the work generated a data bank which will likely be used in subsequent projects. The prototype computer programs can be considered as a product of the project, as can the general method for drag determination that evolved from the work.

One set of intangible outcomes concerns both participants' greater appreciation and understanding of the other's research situation. The industry researcher achieved understanding of the difficulty in maintaining continuous research in the university with graduate students coming and going. One of the benefits perceived by the university researcher was more effective training of graduate students through their increased familiarity with industrial settings.

Knowledge Utilization. Both university and industry scientists felt the project had influenced the nature of research conducted in their settings. This included both changes in research topics and issues, and changes in research methods and procedures used. The university scientist felt that the research area was one that he would not have been involved in if it had not been for the cooperation of the company. He also felt that participation on the project tended to focus his research interest more on industrially relevant topics.

The industry scientist felt that several new projects were stimulated by this project's activities. The findings of the study indicated that the measurement techniques developed could be used in ongoing company R&D projects. It should be noted, of course, that the industry scientist's work had been primarily basic in nature, and one function that the IUCR grant served was to justify work of this type to his management. Many of the commercial benefits that would accrue to the company would not likely appear until well downstream. The university scientist shared his view that ultimately new products and processes would yield economic benefit to the company.

Personal Outcomes. Both university and industry researchers had quite modest expectations about the potential personal impact of participation in the project. The university professor felt that his participation in the IUCR project would have virtually no influence on promotion, salary, job assignments, or visibility within the university. He did feel that it would somewhat enhance his scientific prestige, but no more so than any other project in which he was involved.

In a similar manner the industry researcher was not overly optimistic about the personal benefits that would accrue to him from participation. He did feel that his prestige among peers in the larger scientific community would be enhanced, and that participation might have some effect on promotion, salary, and visibility to his management.

Both industry and university researchers were generally satisfied with the IUCR project. The university professor was particularly pleased with the opportunity to interact with researchers in industry on technical matters.

There was one issue about which the perceptions of the two co-investigators did not entirely mesh. While sympathetic to the problems of graduate training, the industry researcher expressed some concern about continuity in graduate student support, and expressed an interest in finding a way to ensure that research assistant help was of adequate quality. The university researcher, in turn, felt that the demands of the project were not entirely compatible with the training mission of the university, and expressed concern about certain inflexibilities in project scheduling and expectations. These difficulties should be placed in the con-

text of a larger general satisfaction with the IUCR project.

Policy Issues

The industry researcher endorsed the IUCR program as one worthwhile way to promote university-industry collaborative research. Both scientists urged that IUCR refrain from getting into research areas that were excessively applied in nature. It was felt that IUCR occupied a crucial niche in the research linkage between university and industry.

It was suggested that the government, or the NSF, could explore other ways of fostering university-industry research collaboration. The university scientists suggested that NSF perform some kind of brokering function, to link university and industry scientists pursuing similar lines of work. They also suggested the possibility of summer sabbatical experiences in industry, possibly with federal support.

There were comments about the level of funding available under the IUCR program, particularly from the industry side. The industrial co-investigator, and an R&D official in his company, commented that IUCR needs significant funding to achieve its goals. In summary, all participants gave at least a warm endorsement of the IUCR program and its various features.

Chapter 4

A PROJECT ON FILTRATION PROCESSES

Overview of Project and Participants

This research studied filtration processes in solids separation. The participants sought to increase the efficiency of their filtration system by developing a procedure for separation using smaller filter areas. The participating university was a state-supported university in the southwest; the participating firm a small chemical engineering firm in the northeast. The university researcher, a chemical engineer, had been on the faculty at the participating university for nearly 30 years. He had extensive consulting experience with industry, although most of his professional career had been spent in academic settings. Prominent in his field, he published extensively, and had received several NSF grants during the preceding five years. A member of the participating firm described the university professor in admiring terms:

> He is just quite big for an American. I am quite proud of an American being almost the top dog in this field. He honestly is.

The primary industry principal investigator had recently been awarded a Ph.D. in chemical engineering from the participating university (having studied under the university investigator) and had been with the participating firm only since the beginning of this IUCR project. Most of the experimental work was done by this individual. A second industry researcher, also a chemical engineer, had been with the participating firm for many years and had been informally involved in a prior NSF grant to the participating university.

The project itself was supported by a two-year grant from the NSF. Some funds were given to the company for salaries and equipment development. As of this writing the principal investigators had applied for another IUCR grant.

Prior Cross-Sector Collaboration

Prior University Activities. The participating university department had a long history of interaction with industry. Many faculty members had industrial work experience, and consulting or research relationships had been maintained with various industries. As a university respondent pointed out:

> There is, I would say, a very close relationship from industry to the Department . . . we try and have fundamental approaches leading ultimately to some [industrial] application.

Prior Firm Activities. In spite of its small size, the participating firm had a rich history of support to academic researchers through provision of funds, facilities, or staff expertise. A collaborative research project such as that funded by this IUCR grant was not an unusual experience for the firm. The industry principal investigators, however, had no prior experience in large-scale collaborative research with universities.

Initiation of the Collaborative Project

Preliminary Discussions/Work. Collaboration between members of the participating firm and the university researcher was of several years standing, but was somewhat convoluted in respect to roles and relationships among participants. Collaboration began serendipitously when the president of the participating firm attended one of the university professor's classes. This was a "short course" that was a frequent type of offering by the department. His firm was, at the time, developing a product closely related to research directions being pursued by the university scientist. The professor made a visit to the company, which began a long history of consulting and informal information exchange.

Early in this relationship the university scientist interested an undergraduate in pursuing a senior project in the filtration area. The research was rudimentary, as were the resources and equipment devoted to it (a modified eggbeater was part of the apparatus). The young man went on to work on his Ph.D. at the university and continued his filtration research under the tutelage of the university scientist. After receiving his degree the graduate student moved on to become the industry co-PI on this IUCR project. During the course of the grant, the industry scientist changed his status from temporary employee working on the project to permanent employee of the company.

Role of NSF IUCR Program. The university professor became aware of the IUCR program through NSF personnel. He recognized an opportunity to combine the work that he was doing with that of the participating firm and discussed the possibilities with the firm researchers, who were also enthusiastic about the possibilities.

While the university principal felt that his research in this general area would have gone on without NSF funding, the primary firm scientist felt that the character of the research in his company would have been significantly different. It was his feeling that he would

not in fact be employed by the firm in the absence of IUCR funding. Being of necessity profit-driven, they would not have been interested in research with no visible product and would have had no use for his academic talents. They would have developed their filter on a purely empirical basis and not concerned themselves with the scientific phenomena driving its effectiveness.

Application Process and Internal Negotiations. The IUCR grant was the second NSF grant awarded to these researchers for this project. Application and negotiation with NSF personnel were apparently left to the university researcher. He found the IUCR grant application process to be somewhat different from that of other NSF grants, primarily because of differences in NSF policy for industry and university equipment usage. Questions involving the use of equipment which had been provided to the company through this grant delayed the processing of the request for a second grant. Several requests from the NSF for budget revisions in the second grant request also contributed to the delay.

Project Management and Decision-Making

Team structure and roles in this project were somewhat unique in that the university scientist had served as the dissertation director for one of the firm principals and this project was in many ways a continuation of that recently completed dissertation. This created a bifurcated management and communication style within the project in which the firm principal worked independently, yet regularly sought the advice of the university principal in a manner quite different from the consultations sought by the other industry researchers. In addition, different research objectives between the industry and the university (i.e., production versus basic science orientations) were reflected in the principals' management styles.

Project Structure. Although there were many participants in this project, the bulk of the empirical work was conducted by one individual, the primary industry investigator. The working relationship between this industrial scientist and the university professor was initially very like that of Ph.D. candidate and dissertation advisor, and it was in fact an extension of that former relationship. As the project developed the industrial scientist took an increasingly independent role.

While the university team was formally composed of only the university professor and one graduate student, several other university faculty participated at one time or another in a rather fluid manner. There was no formal company team. Participating as needed were technicians, draftsmen, and a company design group for instrument development. The secondary principal played a dominant role at first and then diminished his part as the primary principal gained experience.

Management Style. Researchers participated equally in project implementation. Goals were established and broad scheduling accomplished with the participation of all team members, and most researchers seem to have worked independently within the context of those decisions.

Management style within each team, however, appears to have differed somewhat. While the university researcher delegated authority for scheduling and work allocation to a research scientist on his team, the primary company researcher worked autonomously. A second level of management appears to have existed within the firm in that this researcher was required to submit regular progress reports to the secondary firm investigator. This may have been a pro forma type of reporting, however, and receipt of these reports is the only function, in addition to some administrative tasks, evident for the secondary principal.

It is interesting to note that the university researcher's perception of his most important managerial function was that of evaluating the work of team members, while the primary industry researcher indicated dissemination of results as his most important managerial function. Clearly, contrasting managerial styles among principals in this project reflect the basic-versus-applied science schism historically exhibited in industry/university interactions, as well as an extended student/advisor relationship between the principals.

Coordination

Coordination within this project appears to have been more a function of ad hoc advice and consultation than of scheduled interaction. This may have been due in part to the student/advisor relationship enjoyed by two of the principals and partly a reflection of the primary industry researcher's autonomy.

Coordination Within the Project. Coordination between the two principals was frequent and ad hoc in nature. When the firm scientist wished to discuss data analyses or interpretation, the university professor made himself available for advice. The firm scientist had relatives whom he visited in the university community and this also contributed to frequent informal meetings. Consultations were apparently confined to general and theoretical matters, specific decisions and procedural problems being handled by the firm scientist working alone. In the words of the industry principal:

> . . . he [the university principal] knows in general what I am doing, what is the scheduling, but he has no way of knowing about the specific things.
>
> . . . initially, there is an interface, and then less interface, and usually you see him at the end of each

phase, to tell him . . . what happened, and to discuss with him in detail what happened in the last three months or something.

Communication within the project as a whole was frequent and fluid, particularly in terms of presentation of results. As described by the university researcher:

> . . . we're in contact back and forth with papers. I've had some of the manuscripts [which were] written up there first and then sent down to me to redo. I've done some manuscripts and sent them up there for them to look over and add their thoughts to. And we send copies of experimental work we do up to them to look at and they send work down to us.

Coordination and Reporting External to the Project. Any coordination external to the project which may have existed was certainly not formalized. The company involved was small (less than 150 employees) and an atmosphere of open communication seemed to be the norm.

Benefits and Outcomes

Technical Outcomes. All principals agreed that the most important technical outcome of this research was knowledge gained in the field of filtration research. In particular, they learned fundamentals related to the equipment, data necessary for evaluation, design methods, limitations on equipment use, and optimization techniques.

The increment in knowledge achieved by this research was important to all concerned, primarily because of the underdeveloped nature of this field of inquiry. The primary firm researcher had experienced a great deal of difficulty in his dissertation research because of the dearth of literature in the field; the large number of publications that resulted from this project have apparently contributed a great deal to that knowledge base.

An equally important outcome of this research was the shift in research interest observed in the participating firm. This project has apparently stimulated an R&D capability within the company and an increased interest in a scientific approach to product development. In the words of the principal firm scientist:

> One thing is, the attitude of the people in here has changed completely. Before, I mean, they just worked on empiricism.

Knowledge Utilization. Information resulting from this project has been widely distributed and has significantly affected present and future firm operations. The university principal presented a large number of lectures and short courses on the subject, resulting in over a hundred requests for information, and had frequent communication with Japanese and European researchers and businessmen interested in the process. The results of the project have had a tremendous impact on the participating company's operations. Project results have influenced product design and have become an integral part of testing routines. Both co-investigators believe that there is more to be learned in this area and expect some rather stiff competition from Europe and Japan.

Personal Outcomes. Both principal investigators anticipated increased prestige among colleagues and in the larger scientific community as a result of the project. The primary industry researcher gained a great deal through this research: increased visibility in the scientific community; increased research opportunities within his firm; and his permanent position with the firm itself. The university investigator was given a prominent award by a professional society in recognition of his work.

Policy Issues

All researchers were enthusiastic about opportunities for joint research afforded by the IUCR program and welcomed such collaboration as long overdue. University personnel in particular were encouraged by what they perceived as a growing interest on the part of industry in such research. As one of the university resondents put it:

> . . . the attitude of industry, large and small, is beginning to change quite substantially. A few years ago—lets say ten years ago—government funding was just going gangbusters. And if you talked with the industry, American industry, about cooperative work with the universities, that was just a foreign idea. Today I think the industry is beginning to say, if it's going to be done, we're going to help fund it.

The industry/university collaboration was particularly important to these researchers in light of what they perceived as an abundance of industry engineers lacking training in the fundamentals of their fields. The university scientist in particular felt that the "classic problem of not having the various links in a chain necessary to solve problems" lends itself very easily to solutions through collaborative research and, at the same time, collaboration softens the rather polarized viewpoints of industry and universities regarding basic and applied research. As the university researcher put it:

> I have a very difficult time differentiating between the practical and the theoretical myself. I think you might find that a century ago that you would have had a great deal of difficulty in seeing [a researcher] as a mathematician or an engineer or a chemist or physicist or what because they looked at problems in their entirety and went and tried to solve those things that were needed to be solved, but [they] were really being philosophical.

University and firm personnel alike saw the IUCR program as a vehicle for reducing this apparent schism in research interests and were particularly gratified by the changes in attitude and performance which took place in both the participating firm and the university as a result of their collaboration. A member of the participating firm put the analysis in more graphic terms:

> The theory of universities is, you know, like a dream. It is idealistic and over here we bring it down to reality because you are not going to run it. The customer is going to run it, who bought it, and if the damn thing does not work they are going to give it back. . . . There is a gap there; it is being narrowed down a hell of a lot by the university/industry approach.

The university researcher had some observations on the status of U. S. industrial research. It was his feeling that corporate emphasis on short-term profits effectively stymies long-range research:

> . . . if you are aimed at short-term results, you will never support long-term education research. . . . there's no way, if a company is trying to optimize their profits . . . that you can justify any kind of investment in education when the results come out six or seven years later.

Moreover, he felt that more rapid industrial development would be possible in this country were there more continuity and coordination in university research pursuits. He believed that a balance between group and individual undertakings, where a continuity of effort is maintained over time, is more conducive to advances in scientific research and, what is certainly as important, training of young researchers to fill the shoes of their older predecessors.

While not related to IUCR per se, both researchers addressed one issue: the threat of foreign technological competition. Each felt that the Japanese and Europeans were moving much more rapidly and astutely in exploiting this research area. The university scientist commented on the ease with which his foreign colleagues were able to obtain resources to pursue technology development. One of the firm principals expressed apprehension about his company's developments being copied and exploited by foreign visitors.