Triple Helix VIII: International Conference on Government, University & Industry Linkages
Madrid, Spain, 20 - 22 October 2010

10 Sept 2010

Fostering Team Science:
Innovative Leadership Practices in NSF Industry/University Research Cooperative Centers

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Abstract

The U.S. National Science Foundation (NSF) Industry / University Cooperative Research Centers (IUCRC) Program, like many government-industry-university (Triple Helix) research organizations, incorporates collaborative teams of scientists, or *team science*. The NSF IUCRC Program represents a successful *social technology.* This qualitative study analyzes selected, innovative leadership practices introduced to foster team science at IUCRCs at two levels of leadership – Program and Center – around three dimensions of innovation: *fidelity* to the social technology's core principles, *costs* of resources and coordination, and *efficacy* for valued outcomes. Consistent with earlier research, examples of high-fidelity, low-cost, high-efficacy innovative practices in Center meetings appear to have diffused widely through IUCRCS, including an adaptation of the nominal group technique and poster sessions. An innovation with fidelity to core program principles, but relatively high costs – multi-university Centers – diffused with support by financial incentives introduced at the program level. An example of a reinvention low on both fidelity and efficacy – electronic attendance at Center semi-annual meetings – has not diffused. These preliminary, qualitative results raise questions for the science of team science, and if corroborated, carry implications for leaders aiming to foster team science in triple helix organizations.

Key words: Cooperative research centers; innovation; leadership; team science; science of team science; social technology; triple helix.

The authors acknowledge financial assistance provided by the Department of Psychology, College of Arts and Sciences, and Office of Research, at the University of Tennessee, Knoxville, TN, U.S.A. and by the National Science Foundation Industry/University Cooperative Research Centers Program (EEC-0631414) and its Science and Technology Centers Program (CHE-9876674) in preparing this paper

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1. Introduction: Innovation in Fostering Team Science in Cooperative Research

Organizations for government-led, industry-university cooperative research – or *Triple Helix* collaboration (Etzkowitz & Leydesdorff, 1997; Etzkowitz, 2008) – increasingly rely on teams of scientists. In other words, these organizations incorporate what has widely become known as *team science* (Boardman & Gray, 2010; Gray & Sundstrom, 2009; Stokols et al., 2008; Sundstrom 2009). Team science has expanded to the extent that in some fields, multi-author, scientific publications now outnumber single-author publications (Jones, Wuchty & Uzzi, 2008; Wuchty, Jones & Uzzi, 2007). Triple Helix organizations for scientific research have also expanded globally (Wagner & Leydesdorff, 2005), particularly university-based Cooperative Research Centers (CRCs) that seek technology transfer to external, sponsor organizations from industry (Gray, 2008).

We focus here on one, long-standing, government organization for industry-university cooperative research, the U.S. National Science Foundation (NSF) Industry / University Cooperative Research Centers (IUCRC) Program. Since the late 1970s NSF has offered small grants for universities to establish Centers hosting programs of pre-competitive, industry-funded, scientific research on selected, leading-edge technologies (Gray & Walters, 1998). NSF provides guidance, oversight, and on-site evaluation oriented toward continuous improvement and organizational learning (Gray, 2008). Host universities provide facilities and staff, and faculty scientists and students to do the research. Research guidance at each Center comes from an Industrial Advisory Board (IAB) comprised of representatives of the sponsoring, member organizations that provide primary funding. NSF has launched more than 110 IUCRCs since 1980. In 30 years the IUCRCs have generated an impressive series of technology breakthroughs (Scott, 2007, 2009).

The NSF IUCRC program represents a successful example of a *social technology* (Gray & Walters, 1998), or a knowledge-based, demonstrably replicable system of roles, policies, practices, and procedures for achieving specified outcomes (Tornatzky & Fleischer, 1990). The IUCRC program sought from its outset to produce 3 outcomes: "...industrially relevant, fundamental research, education, and technology transfer" (Gray & Walters, 1998: 15). The initial design of the IUCRC program drew from research and theory on organizations and their development (Aldrich, 1977; Cummings, 1984; Katz & Kahn, 1978) to specify the program's structure of role relationships, founding membership agreement, basic policies, and initial operating procedures. However, since social technologies are very context dependent, the NSF IUCRC Program has evolved and adapted to a changing environment since inception, through innovations introduced and reinforced at multiple levels by its leadership, and documented through its integral evaluation program (Gray, 2008).

In this paper we describe a qualitative, exploratory study of innovative leadership practices designed to enhance performance by fostering team science at IUCRCs. Such practices represent re-inventions of a social technology via reactive responses to environmental pressures, and/or proactive initiatives toward improvement. We analyze cases from the IUCRC Program in terms of 3 dimensions of innovation potentially related to their diffusion, the extent of their adoption throughout the Program's Centers. First, *fidelity* to a social technology's core principles (Rice & Rogers, 1980; Rogers, 1983), has been found positively correlated with effectiveness of innovations that introduced constructive reinvention in selected, public, social programs (Blakely, Emshoff & Roitman, 1984). However, innovations that eliminated or negated core features of the social technologies, thereby undermining fidelity, produced poor results. A second key dimension, *costs* of innovation, include requirements for added resources and coordination. Third is *efficacy* for achieving valued outcomes. Based on earlier research, we expected widest diffusion of innovative leadership practices in NSF IUCRCs with high fidelity to the program's core principles, relatively low costs, and efficacy for mission-critical outcomes, and as shown by subsequent adoption at other Centers. In brief, we expected to find diffusion of examples of practices representing high-fidelity, low-cost, high efficacy reinvention of the social technology.

This paper has four more sections. The second gives background on the IUCRC Program leadership structure and core policies. The third section describes our method: exploratory case analysis of innovative practices at current IUCRCs and "graduated" (no longer NSF-funded) IUCRCs. A fourth section analyzes examples of program- and Center-level, innovative leadership practices in two areas: 1) expanding multi-discipline, multi-institution collaboration; 2) new communication forums at Center semi-annual meetings. A fifth and final section offers conclusions and open questions about fidelity, reinvention, and diffusion of innovative leadership practices, and implications for team science in cooperative research organizations.

2. Background: NSF IUCRC Program's Leadership Structure and Core Policies

In executing its three-part mission of industry-relevant research, education, and technology transfer, the IUCRC Program resembles a national franchising operation for industry-university CRCs. NSF offers small, annual funding awards, renewable up to 10 years, to host universities willing to sign the basic, NSF IUCRC membership agreement. It specifies university ownership of Center-developed intellectual property (IP) and technology, with unlimited access for the industry stake-holder organizations, which have non-exclusive, royalty-free license to use the Center-developed IP and technology. The agreement requires the university to waive most of the usual overhead charges in research contract research. NSF also requires each Center to maintain a minimum level of financial support by industry members, substantially greater than the NSF award, thereby making the industry stake-holder organizations into a primary source of funding for Center science.

2.1. NSF IUCRC Program Leadership Structure

The NSF IUCRC Program requires collaboration at multiple levels (Gray & Sundstrom, 2009). Besides the basic unit of team science, the project team, IUCRCs have leadership at the Program and the Center levels.

2.1.1. Program leadership. At the national office, the program director leads a small team of co-directors and staff members. They prepare solicitations for proposals for new IUCRCs, invite proposals from selected universities, organize review panels that decide which new Centers to fund, oversee the operation and evaluation of funded Centers, and review IUCRCs for annual renewal of funding. The national program leadership team can create program-wide, financial incentives for adopting and following new practices at the IUCRCs. (For example, the NSF IUCRC Program offers incentives for Centers to recruit small businesses as member organizations by offering grants to subsidize almost all of a small business's membership fees at a Center for two years.) Program leaders can also incorporate innovative practices into solicitations for proposals for subsequent cohorts of IUCRCs, which host universities agree to follow when accepting research grants. In effect, the program leadership can re-design and re-invent the program in new cycles of operation.

2.1.2. Center Director. The key IUCRC leadership role – Center Director – reflects the complexity of the Center structure (Gray & Walters, 1998; Craig et al. 2009). It calls for effectively managing relationships with representatives of the government program, member-sponsor organizations, and the host university administration, faculty scientists, and students. At a single-university IUCRC, the Director leads a management team comprised of an administrative coordinator, and possibly a bookkeeper, marketing co-director, and/or research co-directors.

The Center director's role involves taking the lead in recruiting member organizations into the Center (Gray & Walters, 1998). This role begins before a Center receives NSF funding, because a minimum IUCRC proposal requires at least 6 to 8 member organizations committed to funding the Center's research. When a prospective Center director succeeds in winning an NSF IUCRC award, the new director's role demands continued leadership in recruiting members, for growth of the Center and for replacement of member organizations that withdraw. Historically IUCRCs have had member turnover averaging 10% per year (Gray & McGowen, 2010). For the 45 NSF IUCRCs funded in 2009, the combined, lifetime membership turnover amounted to 48% (Gray & McGowen, 2010).

The role of Center director calls for taking the lead in organizing, supporting, and fostering team science at the Center. This in turn calls for initiating and maintaining a Center infrastructure that supports leadership at two levels:

2.1.3. Center Industrial Advisory Board. An IUCRC IAB, composed of representatives of dues-paid, sponsor organizations, has an elected chairperson. The NSF award requires each IUCRC to host semi-annual, face-to-face IAB meetings in which the Center's university scientists report the progress and results of their research, with proposals for further research. These meetings typically last one to two days and take place at a Center university site. Led by its chairperson, the Board reviews Center research, allocates funding for future projects, and offers guidance to the scientific agenda.

2.1.4. Research project teams. In an IUCRC the basic unit of scientific collaboration is a project team at a university laboratory, led by a faculty scientist (the project's principal investigator), with one or more graduate students, sometimes others, including other faculty scientists and students, technicians, laboratory staff, and/or industry scientists or technicians. Historically, the simplest configuration for an IUCRC project team – one faculty scientist working with one or two graduate students from the same academic discipline – has been the most common (Gray & Sundstrom, 2009).

2.2. Core IUCRC Program Policies & Practices

From its outset, the NSF IUCRC Program has sought to achieve its mission by incorporating a coherent, minimal set of policies and standard practices designed to promote scientific cooperation within Centers. Cooperation is based on the standard membership agreement and a defined leadership structure. The resulting social technology has amounted to a national IUCRC research franchise implemented in a more or less consistent way at each Center. IUCRCs have autonomy in developing their own programs of scientific research on the particular technologies they investigate, and their own, local bylaws for shared governance. However, the IUCRC Program includes a few core practices besides the basic membership agreement and leadership structure, built into the funding agreement between the government program and the host universities: annual program meetings; semi-annual Center meetings; and an integral evaluation program.

2.2.1. Annual IUCRC Program meeting. As a primary vehicle for communication among the Centers, the Program hosts an annual conference of current and "graduated" Center Directors and Evaluators, administrative coordinators, and NSF program leaders. The meeting provides a formal vehicle for communicating new learning about and from IUCRCs, best practices, new NSF funding initiatives, program changes, and other news. The meeting is also consciously designed to maximize opportunities for informal exchange among Center directors, as a way to foster conversations about innovations and aid in their diffusion.

2.2.2. Semi-annual Center meetings. As the primary vehicle for formal industry-university communication and cooperation within Centers, and to create opportunities for informal communication, each IUCRC must host a semi-annual meeting of its industry member representatives – the Center's IAB – and its scientific project teams, including students. At each meeting the project teams formally present their scientific work and propose future projects. In closed-door sessions the IAB reviews the research, offers guidance to the scientists, and sets priorities for funding in their advisory role for the Center director.

2.2.3. Integral evaluation program. The IUCRC Program's internal system for evaluation provides on-site monitoring of IUCRCs for fidelity of implementation; documents their operations; and collects data oriented toward program-wide learning and continuous improvement. The evaluation program draws on annual reports from IUCRC Directors, which NSF requires each year for Centers to renew their funding awards. Directors report on their Center's structure, finances, personnel, and outcomes, including scientific publications, educational accomplishments, and technology transfer. The evaluation program analyzes the data from all IUCRCs nation-wide and produces annual program reports (e.g., Gray & McGowen, 2010).

Each IUCRC also has an independent, paid, on-site evaluator, who collects data from scientists and industry member representatives for a national database. Evaluators also file standard, annual, narrative reports documenting each Center's activities, environment, key events, and results (Gray & Walters, 1998; Gray 2008). The evaluation program has archived these reports, which provide a source of data for research like the present study.

3. Method: Qualitative Case Analysis of Innovative Leadership Practices at IUCRCs

In the present exploratory, qualitative study we drew from the program's national, cumulative evaluation archive, for cases in two selected areas of innovation. For case analysis we drew on evaluators' reports concerning the current, active IUCRCs with NSF funding through 2009. We focused mainly on examples from the 10 active Centers for which one of us serves as evaluator. For innovative practices introduced in earlier years, we drew on case examples of IUCRCs no longer funded by NSF, called "graduated" Centers.

3.1 Current NSF-funded IUCRCs. In 2009, NSF funded 45 IUCRCs, including eight new Centers launching in 2010, with a combined total of 124 university sites and 695 industry memberships (some sponsor organizations belong to multiple IUCRCs; Gray & McGowen, 2010). The average, NSF-funded IUCRC in 2009 had 2 or 3 University sites, 19 industry member organizations; 16 faculty scientists, 2 or 3 post-doctoral scientists; 15 doctoral students, and 12 master's degree students (Gray & McGowen, 2010).

3.2. Graduated IUCRCs. Of approximately 70 IUCRCs launched by NSF and no longer receiving NSF IUCRC funds, about two-thirds became self-sufficient. The population of active Centers includes 45 graduated IUCRCs operating with industry funding (McGowen, 2010).

Qualitative analyses can potentially draw on a combined population of 90 current, active, NSF funded and graduated IUCRCs for examples of innovative leadership practices.

4. Preliminary Findings: Innovative Leadership Practices in NSF IUCRCs

We identified case examples in three selected areas of team science-related reinvention: 1) expanding multi-discipline, multi-institution collaboration; 2) introducing innovative communication forums that use information technology to substitute for face-to-face Center meetings, or to promote face-to-face, formal and informal interaction among Center collaborators. As described below, reinvention congruent with core principles tended to diffuse to other Centers, sometimes becoming routine practice, while innovations that undermined core principles proved less widely accepted.

4.1. Expanding Multi-Discipline, Multi-Institution Collaboration

Since inception, the NSF IUCRC Program has sought to foster multi-discipline collaboration, toward new knowledge reflecting synergistic combination of separate, specialized disciplines (Gray & Walters, 1998; Gray, 2008). This goal reflects a trend toward *transdisciplinary science* "...that synthesizes and extends discipline-specific theories, concepts, methods" (Stokols, Hall et al 2008, p. S79), now influential in engineering (Boardman & Gray 2010). The NSF IUCRC Program has sought to advance its mission of industry-university cooperative research by encouraging multi-university Centers and multi-discipline science.

4.1.1. Multi-university IUCRCs. In an early, program-wide, IUCRC innovation, leaders at NSF initiated a series of new practices to promote multi-university Centers. The first multi-university IUCRC launched in 1985, five years after the first single-university IUCRC opened. Through 1990, multi-university IUCRCs represented less than 10% of the all IUCRCs. In the 1990s, NSF program leaders began to actively encourage multi-university proposals, and announced priority funding for multi-site IUCRCs. By the year 2000, IUCRC grants included small incentives for multi-university IUCRCs, which had expanded to 40% of all IUCRCS. The proportion of IUCRCs at multiple universities continued to rise. In 2009 the revised IUCRC solicitation added another incentive for multi-university IUCRCs: it set the minimum membership requirements for single-site Centers at $400K per year, or $50K higher than for multi-university Centers. As of the end of 2009, multi-site Centers represent more than 80% of currently funded IUCRCs.

The conversion to multi-university IUCRCs represents a high-fidelity re-invention of the original IUCRC program, introduced through leadership practices and incentives at the program level. The innovation extended the original program to incorporate inter-institution collaboration, while retaining all of the program's core elements. Widespread adoption of an innovation consistent with core principles to extend their reach agrees with the results of research by Blakely et al. (1984) – with an important caveat concerning costs of innovation, and an open question concerning efficacy.

Multi-university IUCRCs require coordination among their sites, adding organizational complexity and increasing operating costs for the Centers and the Program. Each multi-site IUCRC has an extra level of organization: a site director and site management team at each university to serve as the designated PI for the NSF IUCRC award to that site. At each university site, the director leads a team comprised of the Center's administrative coordinator, research program leaders, and others who help manage the research program on campus. The average IUCRC now has 2 or 3 university sites. An IUCRC executive director at the primary university site leads an executive team comprised of the site directors. Does the investment in more complex, multi-site IUCRCs enhance Center outcomes? While this question remains unanswered for IUCRCs, research by Cummings and Kiesler (2007) suggests that multi-site Centers might reduce program performance due to the added organizational complexity and coordination costs. This IUCRC reinvention deserves close monitoring.

4.1.2 Multi-discipline science. At the Center level, IUCRC directors have routinely encouraged multi-discipline cooperation, for example by inviting proposals from faculty-student teams from different departments and/or colleges. As a consequence, most IUCRCs have multi-discipline research portfolios of projects conducted by faculty-student teams from several academic units.

Historically, the simplest configuration for an IUCRC project team – one faculty scientist working with one or two graduate students, all from one academic unit – appears to have been most common (Gray & Sundstrom, 2009). Multi-discipline project teams, comprised of two or more faculty scientists from different disciplines and/or academic units, have been less prevalent. For example, at a 2010, semi-annual meeting of Center S, a 2-university, IUCRC, scientists presented 16 projects, of which 12 had teams led by single faculty investigators working with 1 to 3 graduate students per team and, in some instances, post doctoral and/or industry scientist co-investigators. Just four projects, or 25%, involved two faculty scientists. In 3 of these teams, the scientists worked from the same academic unit, as multi-investigator, single-discipline teams. One multi-faculty-investigator team also included two industry scientists. In all, 2 of 16 scientific project teams (13%) could reasonably be described as multi-disciplinary.

Why would multi-discipline project teams be relatively rare in a multi-discipline IUCRC? Among other reasons, single-discipline, single-scientist project teams have advantages of simplicity, efficiency, and expediency. Small, faculty-led teams can work from one laboratory with the university scientist supervising students from an office nearby. Multi-investigator teams, especially from multiple disciplines, require more coordination, which in turn brings other challenges for team leadership (B. Gray, 2008). Among others, the challenges include mutual education about the disciplinary perspectives, concepts, methods, and differences associated with various forms of diversity (Bennett et al. 2010).

A few IUCRC directors introduced innovative leadership practices to encourage multi-discipline research, and sometimes multi-discipline project teams. These include: a) inviting industry scientists to serve as co-investigators in Center project teams; b) establishing testing laboratories for multi-discipline research, and c) making multi-discipline collaboration part of the Center mission, including participation in multi-discipline degree and certificate programs.

• Industry scientists as co-investigators in project teams. At some NSF IUCRCs the IABs work with their Center directors to designate industry scientists as project mentors. For example, the IAB at Center S, in cooperation with the director, identified industry scientists as mentors for each project, usually from the member organization providing primary funding. The scientists invited the industry scientists serving as mentors to work as co-investigators, and conduct the projects partly at industry facilities. At Center S project teams with industry scientist members (mentioned above) the industry scientists have different, but relevant, scientific specialties. At least one other, active IUCRC, Center H, follows the same practices. This high-fidelity, low-cost, potentially effective innovation seems likely to diffuse.

• Testing laboratories for multi-disciplinary research. To support an explicit commitment to inter-disciplinary research, current Center R built a leading-edge testing laboratory near the campus of its lead university site. The goal was to attract scientists from the many disciplines represented among the Center's industry member organizations for on-site research projects. Center R followed precedent in the IUCRC Program. One of the first five IUCRCs, graduated Center W, built a testing facility near the campus of its lead university. It became a site for international, collaborative projects, and operates today. At least a dozen other IUCRCs have opened similar facilities.

Establishing testing laboratories for on-site, multi-discipline projects has become a widely diffused practice among IUCRCs, though this practice has sometimes fostered an unexpectedly basic form of multi-discipline team science. At Center P, one of more than a dozen, active, NSF-funded IUCRCs that operate international testing facilities, Center scientists published a total of 26 articles in professional journals in calendar years 2008-09 describing the findings of Center-funded research conducted at its testing facilities. Twenty of the articles, or 77%, represented single-discipline projects co-authored by one faculty scientist and one graduate student or post-doctoral scientist. Two more were single-discipline articles with one faculty scientist and two graduate students and/or visiting scientists. Only 4 articles described multi-discipline collaborations (15%). At this Center the multi-disciplinary research involved mainly small, single-discipline projects, or what could be called *one-discipline, small team science.* The prevalence of one-discipline, small team science versus larger, multi-discipline project team science, at IUCRCs and their testing facilities remain an open question for future research. For now, it appears that testing labs have supported research from multiple disciplines, but not necessarily multi-disciplinary research projects.

• ***Multi-discipline collaboration as part of Centers' missions.*** Extending the usual, cooperative mission of an IUCRC, current Center H adopted "multi-disciplinary diffusion of knowledge" as part of its formal mission, focused on knowledge-sharing between practitioners and scientists. Center H actively supports multi-discipline research project teams through the Center's participation in formal, inter-department degree programs for graduate students and – for scientists – formal, interdisciplinary certificates. Some IUCRCs expanded their missions to include development of human capital of Center scientists (Boardman, et al. 1999) including capabilities as technical contributors, collaborators, and leaders. For now this innovative practice remains mainly local, though it clearly reflects the education component of the IUCRC Program's mission.

4.1.3. Multi-institution cooperation. The IUCRC Program actively encourages multi-Center and multi-institution cooperation, based on the rationale that diversity of expertise represented at different institutions creates the potential for synergies from collaboration. Leadership practices for fostering multi-institution collaboration have involved initiatives at the Program level – through funding incentives – at the Center level – through allocating funds to multi-institution projects, inviting projects by external investigators from other universities, and participating in cooperative programs for undergraduates at partner colleges.

• ***Program-level, funding incentives for inter-IUCRC collaboration.*** The NSF Program leadership has encouraged multi-institution cooperation by offering grants to fund joint projects between IUCRCs, since 1995. The initial version of this incentive program offered grants for so-called TIE projects, with matching funds up to $100K per year for projects proposed by two Centers whose IABs each offered $50K. The program had many more proposals than it could fund, and it continues today.

The extent to which the program-wide practice of funding multi-Center, collaborative projects has fostered multi-discipline research teams remains an open question. One recent, NSF-funded collaboration between Center C1 and Center H2 involved a multi-disciplinary, multi-institution project team that produced an innovative, national database and supporting software. While the successful outcome of this project is exactly what the NSF program envisioned, it apparently went forward because of the financial incentive. The IUCRC Program apparently has very few, if any, examples of inter-Center, inter-institution cooperative projects funded from within the Centers.

• ***Center-level financial incentives for multi-institution project teams.*** At a current IUCRC, Center F, the director explicitly dedicates a budget from the NSF award (not industry funds) for inter-institution projects, and encourages multi-year proposals. This Center-level practice may be relatively uncommon, as most IUCRCs allocate their NSF funds to supporting their administrative staff and day-to-day operations. The extent to which this practice diffuses to other Centers remains to be seen.

• ***External investigators: Center scientists from other universities.*** At graduated Center M, established in the 1980s, the director invited proposals from selected, off-campus scientists. Center M's Board funded project teams comprised of single scientists and their graduate students from three other universities. Projects at all three, external sites each went on for three or more years, as Center M conducted a multi-university research program without formal agreements with the universities as research sites. One off-campus research team's project eventually received a patent. Another obtained separate, NSF funding for a series of IUCRC projects. The third off-campus team developed a line of research that attracted industry funding for that university to become a site of the Center.

At least two current IUCRC took a similar path. Center C1 invited external investigator proposals and funded a project from another state university. The project represented a line of research that gained enough industry funding to support a proposal for that campus to become a Center C1 university site. At Center W, a two-university IUCRC, current projects include scientists at two other universities. Further diffusion seems likely.

• ***Faculty-supervised, undergraduate interns at partner institutions.*** Some colleges require undergraduates to participate in off-campus projects at local, industrial firms to complete their degrees. The Director of an IUCRC near one such college, Center C1, arranged for a project proposal for a project team comprised of faculty-supervised, undergraduate interns working with an industry scientist at the local facilities of a Center C1 member organization. The Center's IAB approved the project, which required much less funding than usual. This innovative, multi-institution project team had one of its undergraduate intern members report the successful results at the IUCRC's semi-annual meeting.

Overall, both the Program-level and Center-level, innovative leadership practices introduced to foster multi-discipline, multi-institution team science at NSF IUCRCs represented proposed re-inventions high on fidelity to the principles of the original, social technology. The clearest example of an innovative practice that diffused through the IUCRCs involves the conversion of the NSF IUCRC program from largely single-university to mainly multi-university Centers. However, this re-invention was supported by financial incentives, and its complexity adds costs of coordination. For the IUCRC Program questions still remain about the added efficacy of such complex arrangements for achieving program goals.

The forms that multi-discipline team science has taken at multi-university IUCRCs include examples of what we have called *one-discipline, small team science* – single faculty investigators collaborating with their graduate students or visiting scientists from the same discipline. We found this form far more prevalent in the few case examples we described than larger, multi-discipline collaborations. If, as we suspect, the apparently less common, multi-discipline projects carry more coordination costs, it is reasonable to expect faculty scientists to take them on mainly when offered incentives. For now, the prevalence of one-discipline, small team science in the IUCRC Program remains an open question empirical research. Small team science seems to offer IUCRCs an efficient vehicle for cooperative, multi-discipline science via parallel, single discipline projects.

4.2. Innovative Communication Practices at IUCRC Semi-Annual Meetings

As a condition of its NSF award, each IUCRC holds semi-annual meetings at which the scientific project teams present progress reports and proposals for future work to the IAB, in technical review sessions. At these 1- or 2-day events, the IAB then holds a closed-door meeting without the scientists, in which representatives of sponsor organizations discuss ways to refine and support the research projects, decide how to allocate their funding, and collectively suggest directions for the Center's short-term and long-term research agendas.

We identified three categories of examples of innovative leadership practices involving IUCRC semi-annual meetings: a) early adaptation of a nominal group rating technique for IABs to evaluate Center projects; b) applications of information technology for efficient communication; and c) sessions held in conjunction with IAB meetings to promote both formal and informal, face-to-face interaction between Center and Industry scientists.

4.1.1. Adaptation of the *nominal group technique* for IABs to evaluate projects. At the Industrial Advisory Board meeting of one of the first few IUCRCs in the early 1980s, the Center evaluator noticed that some industry representatives dominated the discussion and others contributed very little. To promote more equal participation, the evaluator suggested a procedure that had proven effective for shared group decisions, called the "nominal group technique" (Van de Ven & Delbecq, 1971). It calls for group members to start as a group "in name only" (hence nominal) by silently writing down their suggestions, then meet and share everyone's ideas aloud, round robin, for discussion. At the IUCRC, the vehicle suggested for the silent, written part was a simple rating form, the "Level of Interest Evaluation" or LIFE Form. Each industry representative was asked immediately after hearing each project presented in the technical session to use a copy of this form to indicate a level of interest (not interested, interested, interested with change, or very interested) and write comments helpful in evaluating the research as a part of the Center's research program, including refinements, offers of help, and information about similar research elsewhere. The next day in the IAB meeting, transcripts of all ratings and comments were circulated to all members of the IAB and discussed in turn. The resulting discussion was participative, productive, and expedient.

The Center director and evaluator presented their success story and LIFE Form technique at the next IUCRC Program meeting. The procedure proved popular among IUCRCs, and the program leadership actively encouraged all Centers to adopt it. By the end of the 1980s, members of IABs at practically all Centers were using LIFE Forms in their technical review sessions and discussing the transcribed comments in their closed-door project reviews. This practice became widely diffused and, while not strictly required, was strongly encouraged by the program leadership (Gray & Walters, 1998).

LIFE Forms represented a high-fidelity, low-cost, high-efficacy innovation at IUCRCs dedicated to cooperative research. The procedure assured equal participation by industry sponsors as they cooperatively evaluated Center research projects.

4.1.2. Applying information technology for efficient communication. When advancing information technology enabled electronic LIFE Forms, the IUCRC Program capitalized on the opportunity for greater efficiency. One other innovative use of information technology for IAB meetings, long-distance "attendance," proved less successful.

• Electronic LIFE Forms. In the 1990s, versions of the LIFE Form became available as computer files for printing paper forms. Transcripts were shown on overhead projectors. In the early 2000s, the NSF IUCRC Program commissioned a university to develop and maintain a website where IAB members can enter secure ratings and comments online, and the website produces a summary of ratings with the project-by-project written comments. In 2010, this efficient, low-cost innovation is a routine part of practically every IUCRC semi-annual meeting.

• Long-distance, electronic "attendance" at IAB meetings. When information technology and the internet combined to allow long-distance viewing of video presentations and tele-conferencing, some IUCRCs experimented with long-distance attendance. Center M, for example, broadcasted the technical presentations for one of its 2005 IAB meetings on a secure website for viewing at one of the industry member organizations, and allowed some IAB members to "attend" the meeting via speaker-phone. (The broadcast required substantial effort and added to the financial costs of the meeting.) Both the faculty and industry sponsors at Center M decided the experiment had taught them that long-distance "attendance" did not substitute for face-to-face meeting. Another IUCRC, Center P, tried substituting a day-long phone conference for its IAB meeting as an economy measure when travel budgets were limited in 2008. The meeting had less than 50% attendance. Other IUCRCs did similar experiments, with similar results, which were shared at the national program meeting. IUCRC Program leaders announced that IUCRCs are expected to hold semi-annual face-to-face meetings. The practice of long-distance electronic "attendance" at IUCRC meetings is now largely limited to occasional individuals making brief contributions via speaker-phone.

Long-distance "attendance" illustrates a low-fidelity, Center-level, reinvention. While it allows a limited version of formal communication at IAB meetings, it almost completely misses the informal interaction that IUCRC scientists, students, and industry sponsors value, for many reasons. Among the benefits of membership often mentioned by industry members in the annual questionnaire: professional networking and access to students as potential employees (Gray & McGowen, 2010). As a consequence, this modification to the IUCRC social technology appears to have demonstrably low efficacy, and has been rejected by local Centers.

4.1.3. Sessions in conjunction with IAB meetings. Center directors and IAB chairpersons have introduced three other meeting adjuncts that foster a combination of formal and informal, face-to-face communication: workshops, poster sessions, and field trips.

• Industry-focused workshops & short courses in conjunction with IAB meetings. Center H, a new IUCRC, held a half-day industry workshop with appeal to prospective members of the Center, immediately preceding its day-and-a-half IAB meeting at a resort.

The workshop represented a forum for scientific exchange, recruiting new sponsors, marketing Center-trained students to industry, a vehicle for scientists to present a new line of research the Center had considered adopting, and an occasion for informal interaction. At least a half-dozen IUCRCs held simliar workshops this year in this quickly diffusing practice.

• ***Multi-purpose poster sessions.*** Adopting a practice from professional conferences, several IUCRCs conduct members-only poster sessions where scientists and their graduate students present research projects to member representatives. At Center C, these sessions involve appetizers, drinks, and a "best poster" contest with industry representatives as the judges and creative prizes for the winners. This practice is widespread through IUCRCs.

• ***Field trips to remote sites and / or member organization company facilities.*** To maximize informal, personal contact in relaxed informal contexts (toward enabling BDIs - "beer-derived ideas"), Center F2 organizes field trips bus-rides to locations for "hands-on" cooperation and overnight stays. Some other Centers also do field trips for industry members. However, this relatively expensive innovation has so far spread very slowly.

5. Conclusions & Future Directions: Fidelity, Reinvention & Diffusion of Innovation

The case examples of innovative leadership practices introduced at the NSF IUCRC Program illustrate the continuing dilemma of a social technology: the constant tension between adaptation through re-invention and fidelity to its fundamental principles and design (Rice & Rogers, 1980; Rogers, 1983). The examples also generally supported our initial expectation, partly based on the study by Blakely, Emshoff and Roitman (1984), that diffusion of innovative leadership practices in NSF IUCRCs with high fidelity to the program's core principles, high efficacy, and low costs would show diffusion via widespread adoption in IUCRCs.

A clear example of a set of high-fidelity, high-efficacy, low-cost, innovative practices that diffused widely through IUCRCS is the use of an adaptation of the nominal group technique in IUCRC Board meetings to promote equal participation in group decisions. This practice has apparently made IAB meetings more efficient and participative, and clearly enhances the mission of cooperative research.

Another, more complex example of diffusion concerns the conversion of the IUCRC Program to multi-university Centers. This innovation, introduced at the program level with financial incentives, was adopted at 80% of IUCRCs within 20 years. The added complexity and requirements for coordination have added costs for this re-invention, which have been associated with reduced performance in research at other R&D organizations. Whether the shift to multi-site IUCRCs has improved their efficacy remains an unanswered question.

Encouragement of multi-institution research apparently fostered examples of simpler, more expedient team science than might have been expected. We found relatively few examples of complex, multi-discipline project teams. More common, at least in the IUCRCs we examined closely, is what we called *one-discipline, small team science* – single faculty investigators collaborating with their graduate students or visiting scientists from the same discipline. We suspect that small team science is relatively common at IUCRCs, and possibly other triple helix organizations where scientists have autonomy in forming project teams, because small team science carries few of the coordination costs of larger, more complex project teams. The prevalence of one-discipline, small team science in the IUCRC Program remains an open question, and an obvious priority for future, empirical research.

Also consistent with earlier research, an innovative practice introduced at the Center level that we classified as low on fidelity to the program's core principles and low on efficacy apparently did not diffuse. Instead, electronic "attendance" at Center semi-annual meetings seems to have been largely rejected across the IUCRC Program after a few experiments with it revealed how it fails to reinforce the key principles of this social technology.

In conclusion, our preliminary, qualitative results raise questions for the science of team science, and if corroborated, carry implications for leaders aiming to foster team science in triple helix organizations.

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