AAAS REVIEW OF THE NSF SCIENCE AND TECHNOLOGY CENTERS INTEGRATIVE PARTNERSHIPS (STC) PROGRAM, 2000-2009

EXECUTIVE SUMMARY

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INTRODUCTION

A. Study Objectives

This report summarizes evidence and findings from the American Association for the Advancement of Science's (AAAS) study of the National Science Foundation's (NSF) Science and Technology Centers Integrative Partnerships (STC) program. The study is supported by a merit-reviewed research grant directed at the following three specific assessment objectives of interest to NSF's Office of Integrative Activities (OIA):

a. assess the performance and accomplishments of NSF's STC program against program goals and objectives in research, education, knowledge transfer, diversity, and integrative partnerships;

b. assess the effectiveness of the STC mode of support in addressing important science and technology grand challenges and emerging opportunities; and

c. envision the future of the STC program in advancing U.S. leadership in science and technology.[*]

As a program-level study, the AAAS review is directed at the aggregate activities of the 17 STCs funded in three competitions held between 1998 and 2005-06 (see **Table 1**). The first of these competitions led to the "class of 2000" (*n*=5); the second to the "class of 2002" (*n*=6), and the third to the classes of "2005 (*n*=2) and 2006" (*n*=4). The 17 centers span a diverse set of scientific and technological fields and lines of inquiry. Their activities are distributed over six NSF research directorates, with great disciplinary breadth inclusive of university participants and non-university partners. Excluded from coverage are the 25 STCs funded between 1988 and 1998, and the most recent cohort of five STCs funded in 2010.

The AAAS review is designed to inform NSF's internal consideration of the past, present, and prospective value of the STC program. Further, it aims to contribute evidence that can be used to shape and support future decisions about the program through interactions with Executive and Legislative entities, the academic research community, and other constituencies.

B. Study Scope and Framework

STCs represent a visible outlay within NSF's total research budget, per annum and cumulatively. In FY2010, the estimated total budget for the 17 STCs was $57.77M. This amount was the single largest outlay for any of NSF's seven separately budgeted center programs, representing 20% of total center outlays. Taken together, investments in *all* centers' programs account for approximately 9% of NSF's research expenditures (see NSF FY2011 Budget Proposal). Policy

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[*] The AAAS study has been advised and monitored by a Blue Ribbon Panel (BRP). This panel (membership appears in Appendix A of the AAAS report) was tasked by NSF-OIA with dual roles: first, through three formal meetings and continuing informal exchanges, to offer critical commentary and guidance to the AAAS project team's work and review the AAAS final report; and second, to submit its own assessment of the STC program (AAAS Blue Ribbon Panel, 2010). This separate report draws on findings from the AAAS study as well as the Panel's own expertise, to consider the future direction, design, and management of the STC program.

limitations on the share of center programs' funding within NSF's research budget are perhaps the single dominant factor shaping the requirement that the value of STCs, and indeed of the other center programs, be compared with individual investigator/small group awards.

Table 1. NSF Science and Technology Centers Active in 2009, By Year of First Award

Cohort	*Center Name*	*Acronym*	*State*	*Lead Institution*	*NSF Directorate*
2000	Center for Adaptive Optics	CfAO	CA	UC-Santa Cruz	Mathematical and Physical Sciences (MPS)
2000	Center for Behavioral Neuroscience*	CBN	GA	Georgia State	Biological Sciences (BIO)
2000	Center for Environmentally Responsible Solvents and Processes*	CERSP	NC	UNC-Chapel Hill	Mathematical & Physical Sciences (MPS)
2000	Center for Nanobiotechnology	NBTC	NY	Cornell	Engineering (ENG)
2000	Center for Sustainability of Semi-Arid Hydrology and Riparian Areas*	SAHRA	AZ	Arizona	Geosciences (GEO)
2002	Center of Advanced Materials for the Purification of Water with Systems	CAMPWS	IL	Illinois-Urbana	Engineering (ENG)
2002	Center for Biophotonics Science and Technology*	CBST	CA	UC-Davis	Mathematical & Physical Sciences (MPS)
2002	National Center for Earth-Surface Dynamics	NCED	MN	Minnesota-Twin Cities	Geosciences (GEO)
2002	Center for Embedded Network Sensing	CENS	CA	UCLA	Computer & Information Science & Engineering (CISE)
2002	Center for Integrated Space Weather Modeling	CISM	MA	Boston U	Geosciences (GEO)
2002	Center for Materials & Devices for Information Technology Research	CMDITR	WA	Washington	Mathematical & Physical Sciences (MPS)
2005	Center for Remote Sensing of Ice Sheets*	CReSIS	KS	Kansas	Polar Programs (OPP)
2005	Team for Research in Ubiquitous Secure Technology	TRUST	CA	UC-Berkeley	Computer & Information Science & Engineering (CISE)
2006	Center for Coastal Margin Observation and Prediction	CMOP	OR	Oregon Health and Science	Geosciences (GEO)
2006	Center for Layered Polymeric Systems	CLiPS	OH	Case Western Reserve	Mathematical & Physical Sciences (MPS)
2006	Center for Microbial Oceanography: Research and Education	C-MORE	HI	Hawaii	Geosciences (GEO)
2006	Center for Multi-Scale Modeling of Atmospheric Processes	CMMAP	CO	Colorado State	Geosciences (GEO)

*AAAS site-visited STC.
Source: NSF, http://www.nsf.gov/od/oia/programs/stc/.

The study's analytical framework has three core elements. First, it treats the STC program as one of several possible means by which the Foundation seeks to achieve multiple objectives in research, education, knowledge transfer, and diversity. Second, the framework includes a critical examination of NSF policies concerning the establishment and evaluation of centers. Special attention is given to the National Science Board's (NSB, 2007) stated policy that reviews of center programs should be based on the criterion of "value-added." Third, the study makes new analytical use of what to date largely have been treated as administrative features of the STC program: the low percentage of preliminary or invited proposals that are ultimately funded, and the use of cooperative agreements rather than grants or contracts to fund and monitor centers for up to 10 years.

C. Sources and Types of Evidence

The study has drawn on multiple sources and types of evidence (**Box 1**). The data encompass archival records, interviews with past and current NSF and STC participants; performance data; surveys of faculty and student participants; and independent, commissioned assessments of the contribution of STCs in selected scientific, technological, and educational fields.

Box 1. Sources of Evidence

STC-generated: original proposals; self-reported accomplishments; 2-page profiles; education and knowledge transfer activities; final report from one graduated center; websites; e-mail communications; 2009 and 2010 STC Directors' meetings.

Abt-generated: data reported in 3 summary reports—on international efforts, knowledge transfer, and education efforts—derived from center annual reports and NSF site visit reports; special data runs for AAAS.

NSF-generated: 7 program solicitations (5 STC, 1 ERC, 1 MRSEC*); interactions with OIA & directorate staff; observations at two NSF site visit reviews of STCs.

AAAS: 5 STC site visits; 12 phone interviews with other STC directors; student survey; faculty surveys; 3 commissioned papers and their reviews; research literature and related NSF/Federal reports; student focus groups.

*ERC= Engineering Research Centers; MRSEC=Materials Research Science and Engineering Centers

FINDINGS

STC accomplishments typically involve joint products, or outcomes, such that performance with respect to each objective bears on the performance of the others in fundamental ways. For example, the value-added or transformative nature of STC accomplishments in science frequently relate to new means of knowledge creation and transfer, contributions to graduate and undergraduate education, and integrative partnerships.

A. Science and Technology: Value-Added and Beyond

Two general characteristics underlie the transformative nature of the research conducted by the 17 STCs. First, they typically engage in interdisciplinary, collaborative, inter-institutional research directed at complex, high-priority science-based questions as identified by or reviewed by NSF panels/workshops, National Academies panels, and other national advisory bodies.

Second, in a striking way, perhaps inadvertently obscured by the acronym "STC," their research agendas are rooted in the integration of science *and* technology.

i. Impacts on Research Agendas

STCs are engaged in transformative research in the following ways:

- Changing the scale of analysis or synthesizing across scales (Colorado State University, Boston University, Oregon Health and Science University).

Several STCs noted that their objectives (and accomplishments) were to change the scale of analysis of their traditional disciplines. Capitalizing on new instruments and new data sets, they sought to address questions that lay between or extended beyond traditional boundaries between different research domains.

- Improvements in instrumentation (University of California-Davis, University of California-Santa Cruz, University of Kansas, University of Hawaii).

Two features of STCs make them especially fruitful sources of producing such improvements. First is the high degree of interaction they nurture both among researchers interested in scientific and technological discovery and between this group and prospective users of the new knowledge. Second is their development of user (researcher) oriented instruments of broad scientific impact that, in turn, can serve as *platform technologies* for the customized variants needed to advance field- or location-specific scientific or societal solutions.

- Generating new scientific and technological knowledge relevant to an important U.S./international societal issue, e.g., water; environmental management; cybersecurity; (University of Illinois-Urbana, University of Arizona, University of Minnesota, University of California-Berkeley).

STCs frequently combine advances of knowledge in scientific and technological domains with specific applications to societal objectives. For example, Illinois-Urbana's CAMPWS seeks to change the way the world purifies water by overcoming both academic and policy resistance to altering water research and practice. The work of TRUST at UC-Berkeley contrasts with the DoD and NASA focus on cybersecurity. Instead, these STCs advance the protection of privacy—an immensely important societal concern in today's cyber world.

- Generation of New Platform Technologies/Materials (University of North Carolina-Chapel Hill, Cornell University, University of Washington, Case Western Reserve University).

Development of new platform technologies and materials—those that once existing scientific and technological research obstacles have overcome—hold the potential to contribute significantly to scientific and technological advances across a swathe of fields, as well as to catalyze the growth of commercially important new products and processes. These are the central objectives of the four STCs above.

- Exemplifying a new, fourth paradigm for science (Bell, 2009) (University of California-Los Angeles, Georgia State University).

Advances in cyberstructure to generate new data sets used to model and test scientific hypotheses are now common across many fields of contemporary science. The STC mechanism provides the time and resources required to bring together the domain scientists (e.g., specializing in signal processes and statistics), the technologists, and the user community. This strategic orientation underlies the work of the University of California, Los Angeles' CENS in its efforts to develop pixel/meter-level observation of environmental processes. Likewise, the Center for Behavioral Neuroscience (CBN) played a major role in accelerating the development of behavioral neuroscience as a field. It catalyzed the way brain is studied, and by integrating and advancing neuroengineering techniques, CBN exemplified the science *and* technology aspects of the STC program.

ii. Impacts on STC Faculty

The clearest evidence of the impacts of STCs on the conduct of science relates to the ways faculty behave in their choice or specification of research questions and modes of answering these questions. Survey data clearly indicate that for most faculty participating in an STC, the research they undertake as part of a center and the support they receive from it is only one part of their total research portfolio.

Participation in a center changed faculty behaviors, most visibly in their ability to publish in a different array of peer-reviewed journals. These changes, or effects, accord with the NSB's rationale for the STC program. They reflect increased appreciation of and willingness to collaborate with faculty from different disciplines; in the learning and use of new theoretical models and analytical techniques; and a willingness to participate in collaborative research undertakings. In all, they permit a larger-scale, riskier agenda that concurrently addresses both discovery- and problem-oriented basic and applied research.

The faculty survey data in **Table 2** are reported both separately for "key" participants in the centers (Wave 1, *n*=63) and other STC faculty (Wave 2, *n*=46), and for the total number of respondents (*n*=109). Gauged in terms of conventional research output measures—publications, citations, invitations to speak—49% of the 53 Wave 1 faculty replying to the question report an equal number of publications between their STC and non-STC submitted research, 28% report more publications from STC than from non-STC work, and 21% report fewer publications. Wave 2 faculty responding to the question report a more positive impact on their research output: half of the 38 respondents to the questions indicate that participation in the STC has led to more publications than their non-STC research, while only 18% report a reduction in the number of peer-reviewed publications.

Table 2. Perceived Comparisons between STC and Non-STC Impacts

	WAVE 1 (*n*=63)			WAVE 2 (*n*=46)		
	STC = other	**STC > other**	**STC < other**	**STC = other**	**STC > other**	**STC < other**
Number of peer-reviewed publications	26	15	11	12	19	7
Number of citations	27	17	8	22	11	5
Invitations to speak	21	22	9	14	16	8
Awards/honors	30	12	10	20	10	8
Risk-taking in your research	18	30	4	12	25	1
Research with potential to be transformative	19	30	3	10	27	1

Source: AAAS Faculty Survey, 2010.

Table 3 shows total faculty responses from both survey waves to the question: if there had been a change in their publication behavior. About 40% of the 63 faculty in Wave 1 and 54% of the Wave 2 faculty reported that they were publishing in new fields, with part of this change induced by the availability of new journals.

Table 3. Changes in Publication Behavior of STC Faculty

	Publishing in new fields	New journals available	Seeking to reach a public rather than a technical audience
WAVE 1	**25**	**12**	**7**
WAVE 2	**25**	**7**	**5**
TOTAL	**50**	**19**	**12**

Source: AAAS Faculty Survey, 2010.

Changes in research behaviors may be more substantial and observable in junior faculty— either those newly entering academic positions at the institutions that host or partner with the STC, or postdoctoral and PhD graduates who attained academic positions after a stint in an STC. For these new researchers, participation in an STC has led to increased interest in and appreciation of collaborative, interdisciplinary, and problem-oriented research. They embody a changed research culture. They are also keenly aware of differences in their newly-chosen mode of research with those traditionally associated with individual-investigator, discipline-based research. At the same time, they recognize the staying power of these traditional expectations and academic assessment criteria. Their emergent solution is a simple one: follow a mixed strategy comprised of disciplinary-based, individual work to be published in mainstream disciplinary journals and receptivity to and initiation of cross-disciplinary proposals.

B. Changing Science Education

STCs are ultimately held accountable for executing research-based activities with undergraduate, graduate, and postdoctoral students, as well as precollege teachers and students, as experiments that measurably improve outreach, recruitment, retention, degree-taking, and transition to the workforce. In conjunction with the annual STC Directors' Meetings, the Education and Diversity Directors now meet separately, as well as together with other attendees. The purpose is to share experiences that define the main categories of STC education activities: K-12 teachers and students, research experiences for high school students and undergraduates, graduate and undergraduate course development, and informal science. Clearly, an STC education community has formed.

Table 4 summarizes what the 17 STCs *report* as their education foci, themes, partners, and targets. Approximately one-half report working at all levels of education, cite curriculum and research as core themes, pursue their activities as much alone as with partners, and target K-12 teachers most of all among the external audiences they seek to reach.

Table 4. Summary of STC Self-Reported Education & Diversity Focus

Focus* (K-12, UG, grad)		Themes#		Delivery Partners^		Targeted Groups†	
All	9	Curriculum	9	Organizations	5	K-12 teachers	7
Mostly K-12	3	Research	7	Programs	4	Undrerepresented Minorities (URMs)	5
Undergraduate-Graduate	5	Web	4	None cited	8	Public	4
		Literacy	4			None cited	1
		Careers	4				
		Community building	3				
		Mentoring	3				

* Also noted: postdoc 2; community college 1.
# Multiple responses, so does not add to 17; curriculum includes materials; community building includes networking; mentoring includes role models.
^ Organizations named include Zoo Atlanta; Science Museum of MN; Programs (REU 3).
† URMs specifies a particular minority group (Hawaiians/Pacific Islanders 2; Native American 2; not specified 1).
Source: NSF-OIA, Current Science and Technology Centers, Accomplishments (two-page profiles of 17 STCs submitted Feb-April 2010 by each center).

First and foremost to be recognized is the STCs' major product—new MS and PhD-level scientists and engineers. The program's record of renewing the S&E workforce is stellar. In 2010, half of the STC alumni responding to an Abt survey hold faculty appointments in institutions of higher education and another third are in postdoctoral positions. About two-thirds of the faculty members are on the tenure track, 7% have received tenure, and 4% are already full professors (Martinez et al. 2010: 28-29, Exhibits 4.8 and 4.9).

Graduate student assessments of their STC experiences are positive: 64% report that they are likely to pursue a postdoctoral position. Compared to their non-STC peers, STC students report that the advantages/benefits of affiliation with the STC—experiences, skills acquired, professional opportunities—overwhelmingly outweigh the disadvantages/risks and were more enriching that that of their non-STC peers.

In the precollege domain, a small number of STCs engage in the development of K-12 educational materials, while almost half (47%) of the STC student alumni report participating in outreach targeting the public or K-12 audiences (Martinez, et al., 2010: 19). Overall, however, STC education ventures are bereft of research on teaching, learning, or best-practice interventions. They reflect ambivalence over the perceived NSF injunction to extend their reach into elementary, middle, and high schools, and appear not to be at the core of the STCs' work.

Instead, K-12 education occupied less time and centrality among the various areas of performance.

A summary interpretation underscores the difference between impact and legacy: value has been added in education across the STC Program, but transformations have been limited in terms of the measures conventionally used. This is not unlike what has been observed in the STEM disciplines from which the STCs descend. Nevertheless, the collective experience of the 17 STCs has supplied NSF with examples of broader impacts that might well serve as models for emulation by other NSF programs, center- and non-center-based alike.

C. Promoting Diversity

The central challenge to interpreting performance on diversity is how to calibrate the STCs relative to the home academic departments of participating students. The results of STCs' efforts are modest in (quantitative) terms of attracting individuals from groups not historically participating in science and engineering. But once students *enroll* on campus, STCs are successful in competing for them. Indeed, their diversity—described below—seems broader than the demographics of the disciplines from which the STCs recruit.

Reviews of the STC annual reports and websites reveal that in response to the NSF mandate to diversify the science and engineering workforce, the STCs regard the diversity objective first as a recruitment tool and then as a retention mechanism—critical mass that facilitates degree-completion—for those who join an STC project team.

Through their diversity-oriented activities, STCs are becoming incubators for minority talent, demonstrating that a research field can diversify and become even more intellectually robust, productive, and attractive to students who reflect America's evolving "minority-majority" demographics. The population demographics for underrepresented and non-citizen categories of STC student participants are summarized, in percentage terms, in **Table 5.**

Aggregating the three underrepresented minority groups (African American, Latino, and Native American), the 2000 cohort is the most racially and ethnically diverse undergraduate student population (roughly 43% v. 30 and 36% for the 2002 and 2005-06 cohorts, respectively). The participation of women in the STCs is strikingly higher than the national trend for STEM disciplines: parity with men at the undergraduate level, with a 1.5:1 ratio of undergraduate to graduate women and 2:1 ratio of female graduate students to female faculty. (Little participation or non-disclosure precludes analysis of students with disabilities, NSF's other recognized—by amendment of its statutory authority in 1998 (Public Law 96-516)—"underrepresented" category.)

Table 5. STC Underrepresented Participant Demographics (% of Total)

COHORT	CATEGORY	Undergraduate	Graduate	Faculty	Postdoctoral
2000	Female	51.8%	43.4%	29.1%	29.1%
n=5	Hispanic	11.2%	5.7%	3.3%	3.5%
	Black	31.7%	7.0%	7.7%	2.0%
	Native American	0.7%	1.2%	0.2%	0.9%
	Non US Citizens	7.0%	25.4%	9.0%	45.1%
2002	Female	48.2%	32.6%	15.8%	31.8%
n=6	Hispanic	15.3%	5.9%	4.6%	2.5%
	Black	13.2%	5.6%	3.6%	1.7%
	Native American	1.8%	0.2%	0.2%	0.4%
	Non US Citizens	6.6%	39.3%	13.1%	54.0%
2005/06	Female	48.5%	32.1%	19.4%	27.3%
n=6	Hispanic	8.9%	3.9%	5.6%	7.6%
	Black	23.3%	4.6%	3.6%	3.0%
	Native American	4.0%	0.7%	0.4%	0.0%
	Non US Citizens	1.8%	29.4%	16.1%	48.5%

Source: Compiled from Martinez, A., R.J. de la Cruz, and N. McGarry, Sept. 2010, Exhibits 1-3.

A first-person perspective on diversity in participation trends can be found in the results of the 2010 AAAS and Abt surveys, each of which captured samples of the STC student populations—one current, the other former. For example, in response to the question "Please indicate how affiliation with the STC has proved to be an advantage or not," 54% of current students found "refining my thinking about how gender, race, and ethnicity interact in teamwork" an advantage or benefit, while 88% found "providing contact with many center faculty/researchers" and "allowing exposure to researchers outside my home institution" a benefit.

The establishment of new graduate programs in STC partner universities (especially those that attract minority talent) creates institutionalized pathways for attracting and producing minority scientists and engineers. This takes time, but produces benefits for the disciplines, the host and partner institutions, and the national workforce. It also highlights the importance of allowing for and adjusting for gestation periods in measuring the value-added of a program intervention.

Also understandable is the linkage between education and diversity in the activities of the STCs. But assuming that actions to achieve one objective will necessarily help to achieve the other overlooks several intervening factors known to affect the participation—as students and faculty—of women and minorities (e.g., National Academies, 2010). Nevertheless, hiring decisions ultimately rest with the academic departments.

Several STCs see the research context as a means of transforming smart investigators into multicultural teams whose interactions produce both synergy and novelty. Through the conduit of their educational activities, these STCs embedded diversity at the core of the STC rather than marginalizing it. Evidence of a continuing "legacy" effect on diversity also emerges from the AAAS and Abt student surveys. When current students were asked, "Would you advise new graduate students to join an STC?" the responses "without a doubt" and "probably" yielded 90% agreement. Comparably, Abt asked "Would you recommend the STC to prospective graduate students with similar interests?" and the response was 89% agreement. Regardless of ethnicity or gender, STC alumni and current students endorse the experience.

D. Facilitating Knowledge Transfer

Both by mission orientation and engagement in integrative partnerships, the STC mechanism is predicated on offering distinctive approaches for universities to interact with outside users, and by extension, for knowledge transfer that extends beyond those generally flowing from single-investigator/small group research projects. Partnerships with academic and non-academic institutions and public entities, involvement of industrial and other non-academic specialists on the STC advisory committee, faculty consulting relationships with industry and policy makers, visiting instructorships by industrial scientists, and student internships in industry are among the modes of knowledge exchange used by STCs.

Knowledge transfer activities at centers span a wide range because they are closely aligned with the scientific themes of the specific centers, which themselves are heterogeneous. The principal categories of knowledge transfer activities at the STCs are:

- (a) research findings—publications, presentations, seminars;
- (b) technological innovation— measurable by patents, licenses, products, firm start-ups, and the rest of the conventional set of technology transfer metrics;
- (c) platform science/technologies—new findings that underpin new approaches across a wide set of scientific/technological/industrial fields—measurable by key word analyses; content analyses, patent-publication citations, and the like;
- (d) creation of new institutionalized fields of knowledge—measurable in addition to the above by the establishment of new journals, professional societies, academic departments;
- (e) connections to regional/state economic development activities; and
- (f) impacts on institutional and science policy—traceable, with difficulty, by interviews with key informants, citations to key publications, invited testimony, and related forms of "knowledge utilization."

Based on the 2010 AAAS faculty survey results, knowledge transfer was identified as a net benefit of participation in the STC; and more than 40% of the faculty respondents appear to have participated in the knowledge transfer or product development activities of their center. The AAAS student survey results reveal that more than 80% of respondents felt that allowing their participation in knowledge transfer has been a net benefit. For example, more than one in three respondents to the AAAS faculty survey indicated that their participation in the center had led to more interaction with industry as compared to other members of their department. In the same vein, more than 80% of STC students agreed or strongly agreed with their supervisor/major professor and research group's emphasis on product development (see **Table 6**).

Table 6. Knowledge Transfer—Technology Commercialization Activities, by STC Cohort

	Invention disclosure	Licenses	Start-Ups	Patents	Int'l Patents	Int'l Patents Applic	Patent Applic	Provis-ional Applic	U.S. Patent Pubs	Unavail-able
Class of 2000 Reporting years 1-9	87	4	10	241	9	26	96	35	64	11
Class of 2002 Reporting years 1-7	202	5	13	322	5	4	182	38	58	35
Class of 2005/06 Reporting years 1-4	0	0	0	6	0	0	1	4	0	0

Note: Patents have been sub-classified in their individual subtypes. For the class of 2002 and 2005/06, the numbers reported above are not complete, since these data were missing from the Abt compilation.
Source: Abt Associates Codebook, June 2010.

In summary, STCs engage in a wide range of knowledge transfer activities to achieve maximum effectiveness. This is made possible by the flexibility accorded to the centers by NSF. More importantly, partaking in knowledge exchange at an STC can also result in unpredictable scientific collaborations and outcomes. Thus, by mandating knowledge transfer, NSF receives a higher return on investment—a multiplier effect through mutual sharing of knowledge and resources.

E. Partnerships as Strategy

Partnerships are a defining characteristic of the STC program. As acknowledged by STC directors and participants, no university hosting an STC could undertake the required activities in education and diversity without partners; few institutions could propose the scale and complexity of its research agenda without the participation of faculty at other universities; and several require collaborative relationships with national laboratories, industry, and governmental organizations. Setting knowledge transfer as an objective, and requiring something above and beyond academic publications, likewise requires STCs to engage in partnership arrangements with other, typically non-academic institutions. The motivation for knowledge transfer, that "new knowledge thus created is meaningfully linked to society," is intertwined with the motivation for partnerships.

Each of the 17 STCs included in this AAAS study thus engages in numerous partnership arrangements with a diverse, albeit at times changing set of partners. In this context, partnerships refer generally to formal agreements, in the main involving resource commitments, between the host institution and other institutions—other universities and colleges; firms; government laboratories; school systems; and others.

NSF's solicitations have evolved over the years in the discussion of expectations for types and targets of partnerships. The STC cohorts in this study were the first to be recognized as "integrated partnerships" in the title of the program. However, partnerships have been explicitly acknowledged as part of the STC program from inception.

Lists of potential types of partners have grown with each new solicitation. Some of this expansion is merely the solicitation catching up to the reality—research museums and EPSCoR institutions, for example, were partners in awards before they show up explicitly in the solicitation—but it also reflects NSF's emphasis over time on increasing the participation of a diverse set of institutions.

This study has treated partnerships not as an objective but as *a strategy* employed to achieve the STC objectives in science, education, diversity and knowledge transfer. An enumeration of the number of partnerships depends on the definition employed.

The NSF website listed a total of 121 partners to the 17 centers. Working from the Abt compilation of information in annual reports:

- There were 1694 partners (counting each year separately) for the first 9 years of the 2000 class (an average of just under 38 partners/center each year). The number of partners per center per year ranged from 10 to over 80 in the data as reported, with partners classified as university (36%), industry (24%), federal government (10%), education/outreach (10%), international (9%), state/local government (6%), national lab (3%), and other (2%).

- The preponderance of subawards (90%) was made to universities, suggesting that relationships reported as partnerships on the NSF site were established principally to round out research scope and ensure knowledge transfer. A partner may serve one or multiple objectives of the center, e.g., a liberal arts college or minority-serving institution may be providing access to a diverse pool of undergraduates and have research-engaged faculty; a national laboratory or a private company may contribute special technical expertise and serve as a site for internships.

- While the number and variety of partners varied somewhat with purpose of the center (whether knowledge-driven or product-driven), many of the arrangements are not consistent from year to year (see **Table 7**). For most STCs, many partners (particularly those identified on the NSF website) remain the same from inception.

The data indicate the dynamic nature to the spectrum of partnerships. Not only can institutions in the partnership change, but expectations and roles may change over time as well—further supporting the conclusion that partnerships themselves are not the objectives, but rather a means of supporting other objectives.

Table 7. Length of Center Partnerships for 2000 Cohort

Started	Lasted 1 year		Lasted 2 years		Lasted 3 years		Lasted 4 years		Lasted 5 years	
Year 2	100%	(143)	70%	(100)	59%	(84)	29%	(42)	29%	(41)
Year 3	100%	(79)	63%	(50)	34%	(27)	28%	(22)		
Year 4	100%	(74)	42%	(31)	41%	(30)				
Year 5	100%	(49)	88%	(43)						
Year 6	100%	(22)								

Note: Numbers in parentheses are total count. Year 1 data not included.
Source: Abt report, based on center annual reports.

Obscured in a listing and counting of partners are the motivations for an institution to become a partner. Presumably, a common interest draws participants. The ability to do something otherwise not possible by oneself—physically, intellectually, financially—can be an attractive prospect. But there are costs to such involvement, too—both direct costs to engaging in collaboration and the opportunity costs. A frequent observation made by STC leadership during site visits and interviews was that transactional costs for managing the program are high and relentless. Nevertheless, a consistent theme voiced by STC leaders was that centers generated collective net benefits that took several forms. They included the value of communality of time and space for experts and students from different fields; the ability to address research questions of longer term, wider scope, and more immediate impact (the adoption facilitated by the knowledge transfer emphasis); and the opportunity to create an identity for the center in an emerging/important field—many of which relied on the collaborations and partnerships.

The question of the lasting impact of these arrangements is difficult to answer. Some research relationships were present before the STC was funded (indeed, without any prior relationship, it would be difficult to convince the reviewers that the partnership would be effective). Some relationships are transitory. The dynamic nature of relationships even during the STC award period makes it difficult to ascribe any "lasting" notion of relationship, other than those asserted anecdotally.
The principals involved in the recently graduated (class of 2000) STCs have had considerable success in obtaining ongoing research support, including in center-level grants. Therefore, the partnerships initiated, nurtured or strengthened by STC support can have consequences and yield leverage beyond the execution of the STC mission. For certain aspects of STC operations, however, it becomes very difficult to find sustaining support. In sum, the question of legacy of partnerships is confounded by the difficulties that STCs have in securing financial support to sustain existing or new collaborative activities.

CONCLUSIONS

Given its design as a program-level, retrospective study, this assessment has placed the STC program squarely within NSF's historic mission, evolving objectives, and portfolio of funding mechanisms. Based on the stated criteria of performance, accomplishments, and effectiveness, the study has confronted the challenges of aggregation, weighting, and generalizability.

A. Performance and Accomplishments

The Science and Technology Centers Integrative Partnership Program is an effective and distinctive mode of Foundation support for addressing grand challenges and emerging opportunities in science and technology. STCs serve as the NSF's major funding instrument for supporting emerging fields of science and technology that do not fit within its existing organizational and programmatic structures—including its other existing center programs. Indeed, the array of scientific and technological fields offered up by prospective grantees in response to periodic STC solicitations itself is instructive for NSF's longer-term planning and priority-setting processes, for these proposals represent a faculty-driven, bottoms-up roadmap of what the scientific research community views as high-priority, salient research questions that cannot readily be addressed by existing NSF funding mechanisms.

The influence of the STC program on *scientific and engineering research* has been both discernible and ongoing. The program has:

- Connected the Foundation's core missions and salient, emerging national priorities in science and engineering with emerging trends in the organization and performance of frontier academic research in science and engineering.
- Encouraged, facilitated, and enabled established researchers to enlarge and increase the riskiness of their research agendas.
- Brought together different disciplines, both within the broad fields of science represented by NSF's research directorates and across directorates, thereby contributing to the building of the organizational infrastructure associated with the generation of new research fields and academic programs; and
- Fostered the collaboration of faculty with an orientation towards basic science with those interested in more applied and clinical research.

Above and beyond the specific contributions of individual centers to discoveries in science and technology, STCs were early examples and continue to serve as prototypes for mainstream thrusts of NSF and other Federal science agencies towards high-risk, interdisciplinary, and translational research.
Study findings indicate that debates around the relative roles of individual investigator grants and center grants as modes of funding academic research at times conflate epistemic, philosophical, organizational, and political themes with ground-level observations of how scientists operate. The general trends are clear: cutting-edge research increasingly is taking the form of collaborative, interdisciplinary, and inter-institutional modes of operation. Faculty participants integrate their STC activities with individual investigator activities, and use their STC work as a springboard to future funding.

STC education added value within individual domains, especially in graduate and undergraduate education. Impacts are evident both in the content of program curricula and perhaps more importantly in the training, behaviors, and aspirations of students, especially doctoral students. New degree programs, which by definition must be institutionalized to offer advanced degrees, will endure beyond the NSF-funded life of an STC, adding institutional value.

The program's effects on K-12 education are more difficult to assess. Although specific examples of impacts on K-12 education are observable, the program's scale relative to the size and complexity of systems it is attempting to change is understandably modest. In the 10-year frame of an STC, there is little evidence of sustainable local impacts once project funding ends.

With the chronically woeful performance of the natural sciences, notably the physical sciences and engineering, to attract and graduate women and U.S. citizens of color, STCs loom as entities that promote *diversity*. Participation of women and ethnic/racial minorities at the undergraduate and graduate levels exceed what is typically found in STEM departments. Through educational outreach to middle and high school students (who are more diverse than the adult population), STCs have a singular opportunity to change the face of the U.S. science and engineering workforce. This finding offers lessons for adaptation by other NSF programs, and is part of the STC's legacy of transformation.

Modes for *knowledge transfer* range from the traditional dissemination of information through publications and presentations, to regional economic development through technological innovation and translation, to creation of institutional fields of knowledge through new journals, degree programs, and conferences. These activities are usually built upon existing, new, or fluid partnerships with federal laboratories, industry, non-governmental organizations, academic institutions, museums, etc. STCs serve as focal points, cross-pollinators, and knowledge brokers for effective knowledge transfer within their research communities and beyond, in turn impacting local communities, and influencing regional as well as national policies.

Partnerships are a defining characteristic of the STC program. Each of the 17 STCs included in this study engages in numerous partnership arrangements with a diverse set of institutions. In responding to the NSF requests for proposals, the STCs have employed partnerships as both a strategy and a tactic to fulfill their agendas in research, education, diversity, and knowledge transfer.

While multi-disciplinary and multi-institutional arrangements come with costs of time and effort to establish and maintain, center leadership was consistent in pointing to the benefits in outcomes. The question of legacy is confounded by the difficulties that STCs have in securing financial support to sustain existing or new collaborative activities. For certain aspects specifically associated with the operations of an STC, including the glue that holds centers together, it becomes very difficult to find sustaining support.

B. Looking Ahead

While the STC program's impacts vary across program objective, as suggested above, the concepts of value-added and transformative apply as dominant attributes in a summative assessment of the STC program. In addition, observations made by STC participants in the course of the study flag program performance and accomplishment issues that warrant future consideration: a lack of organizational clarity and ownership of the STC program, ambiguities embedded in NSF principles of program accountability, and procedures for evaluating the program. The report of the AAAS Blue Ribbon Panel (2010) addresses these administrative and management issues in detail.

The STC program exists in an environment characterized by opportunities and challenges. For this reason alone, data and evaluation warrant comment here. NSF's current system for collecting and analyzing performance data is ill-suited for evidence-based decisionmaking. Measures and methods suffer from theoretical and data weaknesses at both the center and program levels. These shortcomings are magnified by episodic pressures exerted upon centers to increase specific outcomes that are not fully consistent with the activities or time horizons of the STCs.

NSF needs to rethink and restructure its approach to *evaluating*, as opposed to monitoring, the program's performance. Data-collection and -analysis need to be tied to specific, precisely-specified, and agreed-upon criteria, metrics, and methodologies that are agreed to by NSF and grantees about the effects of the STC program on stated objectives. Reports based on raw counts and summary tabulations, as at present, provide limited evaluative or planning information.

Finally, means for ensuring that consistency between the criteria, data, and findings produced during the annual center-based program reviews and external, intermittent program level reviews must be established and maintained.

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