Strategies for Arts + Science + Technology Research:
Executive Report on a Joint Meeting of the National Science Foundation and the National Endowment for the Arts

Prepared by
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Workshop Programming Committee

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1. Introduction

The arts and the sciences each contribute to the improvement and understanding of the human condition. Yet, it is clear that these modes of inquiry feature different values, aims, methods, registers and more. Furthermore, they are often posed in opposition to one another, highlighting the largely incommensurate extremes rather than productive synergies that endeavor to serve integrated Arts + Sciences + Technology ends.

In contrast, on September 15th-16th 2010, over fifty-five thought leaders and stakeholders (artists, engineers, computer scientists, and practitioners who straddle disciplinary boundaries) were convened for a two-day interactive discussion about the challenges and opportunities for advances in the creative innovation economy and education institutions. The main goal was to **identify synergies and foster collaborations** across and between constituencies and develop a set of actionable areas of mutual interest: inquiry, collaboration, funding opportunities, lifelong learning, and innovation that are recognized by both the National Science Foundation and the National Endowment for the Arts. The workshop goal highlights the importance of the national intellectual currency that bridges Arts + Sciences + Technology research.

Workshop Objectives

- Identify intersecting points between the Fine, Applied, and Performing Arts and Cognitive Science, Human-Centered Computing, and Computer Science and Engineering
- Develop a gap analysis about opportunities and challenges in the field.
- Foster a dialogue between the National Science Foundation and the National Endowment for the Arts

The workshop format combined structured dialogue, annotated discourse, mind maps, reflective aspirations, and multiple breakout sessions focused on identifying structural and cultural issues in the diverse Arts + Sciences + Technology community. We began with a group session in which participants were each asked:

What is THE big question you are asking about your work, research, institution, and why?
This session oriented the participants toward each other and set the stage for targeted smaller group sessions. Each breakout discussion group was preceded by a roundtable called "Sharing Perspectives" - brief conversations between three or four selected participants. The roundtables introduced topics areas for breakout group discussions in which all participants were engaged.

Sharing Perspectives Topics
- Successful research, creative works and collaborations.
- Chasms and barriers to interdisciplinary research and possible resolutions.
- Best practices in education, pedagogy, and institution policies.
- Technology and cultural trends that are influencing research in the field.
- Best practices for inter-institutional Networks of Excellence

Each "Sharing Perspectives" and breakout group session was moderated by members of the workshop committee with the assistance of graphics facilitation. The workshop notes were aggregated and coded to reveal the major themes and key issues made during the two-day workshop. The result is this executive summary and a workshop Storymap graphic. Additional information about the workshop Storymap can be found at the end of this document.

The workshop culminated with a gap analysis exercise designed to identify the current, desired, and future states of Arts + Science + Technology research community. The gap analysis discussions focused on the following topics:
- **Institutions:** What actionable steps can be taken by lead institutions in scientific research, arts practice and funding?
- **Infrastructure:** How do we identify key infrastructural needs for research in the field?
- **Scholarship:** How do we demonstrate the impact of research in this interdisciplinary field on traditional disciplines?

- **Learning:** What is the role of the academic institution, and non-profit and grassroots organizations in broadening participation in STEM and arts learning?
- **Networks:** How do we move from isolated successes to inter-organizational awareness and collaboration?

Executive Summary

This executive report summarizes workshop recommendations oriented toward a horizon of the next five years, with emphasis on long-term impact and change.

Sections 2-6 articulate the primary outcome of the workshop as brief reports summarizing participants' collective observations recorded on charts produced during breakout group sessions. These report areas are:

Section 2: Successful interdisciplinary approaches in Arts + Sciences +Technology
Section 3: Bridging chasms within and across disciplines
Section 4: Best institutional practices for Science, Technology, Engineering, Art, and Technology (STEAM) learning
Section 5: Significant trends in IT and creative practices
Section 6: Opportunities to develop institutional networks across disciplines

Section 7 summarizes the larger-grained questions that participants individually found to be most urgent. Section 8 articulates commitments to concrete action that participants have voluntarily undertaken. Section 9 concludes by recalling the summarizing observations of the workshop's principle investigators.

2. Successful interdisciplinary approaches in Arts + Sciences + Technology

This session stressed the importance of understanding the fundamental concepts of other disciplines and entering collaborations with both *mutual respect* and a question of *mutual interest* to all. Sparked by discussion of approaches that provide practical knowledge and equipment, open source access to resources, and multi-agency support for preservation of important collaborations between noted artists and scientists, four areas were discussed by participants.

Methods that challenge assumptions and lead to new ideas

Technology and theory should be tightly interwoven, with each driving the other. Theory often proves as a unifier across disciplines. Quick collaborations involving processes such as sketching, rapid prototyping, demos, agile programming and communication are to be encouraged. They can drive results and jump-start ideas for further projects. Furthermore and directly related to NSF guidelines for broadening participation, certain types of proposals could be encouraged/required to collaborate with artists or humanists to enhance public engagement.

Techniques to develop shared terminology

Clearly shared broad and deep readings across multiple disciplines are necessary. However, stress should be placed on *intentional discussions* around unpacking terminology and language. Such intentional discussions should be used, in part, to identify and make explicit the critical purpose of each discourse. After this process, collaborators can parsimoniously name new concepts and artifacts to gain power to articulate insights regarding undiscovered spaces. It must be further noted that building interdisciplinary educational programs supports and forces sharing of concepts/terminology. Finally, advisory boards for collaborations should include a diverse membership to ensure that big questions are asked.

Negotiating multiple values and goals
Clearly, project goals and values could be made very explicit by all collaborators from the outset. Yet, collaborators must be self-critical regarding their own values and goals and the contexts in which completed projects are expected to achieve the goals to be made clear. Relating to NSF guidelines for broader impact, intentional interrogation of power and privilege must be undertaken – whom will this project serve? A type of proposal can be encouraged (often termed "high-risk, high-reward") that emphasizes possibilities rather than assuming that collaborations know what can be done from the outset. Prudence regarding funding of high-risk projects would dictate that proposals be designed for ongoing funding, but start with seed funds. Criteria for receiving institute funding requires evaluation of results, yet it is possible to identify evaluation metrics under which criteria for success are not quantitative, for example the humanities offer many modes of *interpretation* that can enable robust answers to the question "does it create compelling work?" or "does it have substantial impact and contribute new knowledge to society, culture, the sciences or creative expressive forms?" Not all collaborations are successful; from the outset it is important to establish break-up rules and to have agreeable exit strategies for participants.

How to locate and identify collaborations
Recommendations for identifying collaborations were quite aligned. Understanding trends, not as passing fads, but as markers of new social-technical developments is important. Youth cultures and sub-communities are a source of cutting edge application of technical developments and inventions. At the same time, we need to make sure that we constantly build on, and reflect on work, the history of results of workshops such as this one.

3. Bridging chasms within and across disciplines
The root of many blockages within interdisciplinary collaborations is the difference in fundamental philosophical values. Many articulations of these differences have been formulated, one (admittedly not universal) that many agreed with was that art and creative practices favor the specific (building and implementation) and are assessed via subjective interpretation or criticism. Computer science and information science lean toward the general (abstraction and applicability to multiple problems) and privileges assessment and evaluation (quantitative analysis). At the same time, computer science is an amalgam of science, engineering, and mathematics – not a hard science, so it is more amenable to collaboration and invention with the arts. There are diverse

perspectives on the nature of these collaborations and inventions, however, ranging from viewing computers as creating art to simply supplementing it, for example:

- Computer-generated art can be as emotionally moving or otherwise critically effective as human-generated work.
- Computers can be used to expand conventional definitions of what art is.
- Computers are able to represent knowledge and procedures and can amplify human creativity/inscription in multiple media

Regardless of the way collaborations are conceived, the issue of evaluation is crucial to address. New interdisciplinary areas do not have agreed-upon metrics yet, so it is often problematic to make arguments about the importance of particular projects. Discussion of four aspects of bridging the chasm between fields follows:

Interdisciplinary characteristics of Art/Science/technology projects
It may be the case that many successful hybrid projects are initially oriented toward finding problems rather than solving problems – that is, exploratory aims are important. When solving problems is the focus, success must be defined among multiple criteria such as multiple disciplinary practices, epistemologies, and values. The difference between projects with components from different disciplines (transdisciplinary) and projects whose aims themselves lie between disciplines (interdisciplinary) must be born in mind. Projects requiring new ways to view and understand large-grain information are especially ripe for investigation.

Criteria for assessing value – artistic aims
Developing criteria for the evaluation of artistic projects is seen as a challenge that must be overcome for such projects to be deemed appropriate for public funding. However, there is a long standing tradition of forming criteria for assessing artistic excellence. This must be recognized and highlighted. In the arts, critique is a time-honored tradition that is formally implemented through panels for exhibitions called juries. In the sciences, evaluation is accessed through quantitative and/or qualitative methods. The agencies have different review criteria. The NEA rewards "artistic excellence" and the NSF "intellectual merit and broader impacts". At times, evaluation processes from both the arts and sciences are deficient in a similar ways. However, the review processes across the two agencies are more similar than not. They invite panels of experts and peers to evaluate the impact, relevance, and transformational potentials of the proposed projects. Funding programs that support Arts + Sciences + Technology research should remain cognizant of the similarities and differences in how these disciplines validate what they value. They should maintain diverse review panels with people who can translate between disciplines and evaluate without implicit bias for or against a specific culture of knowing. Audience experiences of appropriate projects should be taken into account. Broad dissemination is an important criterion to consider,

though with proper reservation regarding work that is not popular in its aims. Finally, it could be instructive for ethnographers to engage in studies of review panels evaluating interdisciplinary projects to better understand and scientifically document the challenges and successes of such procedures.

Evaluation methods criteria

When hybrid or novel methods of evaluation are used, each must be interrogated and explicitly justified. Even within the sciences, natural versus artificial fields have different criteria for evaluation. The field of artificial intelligence has struggled with questions of evaluation, the outcomes of which may prove instructive for other types of interdisciplinary computing projects. Iterative evaluation models while projects are ongoing can be used as a guide throughout the project. It should be encouraged that evaluation panels in the sciences or the arts should include reviewers from other disciplines. In other words, relevant NEA panels should include Scientists and Technologist and relevant NSF panels should include Artists and Designers. A model for this practice was begun in the NSF CreativeIT program and should be continued in other relevant funding programs.

Success strategies for bridging multiple cultures

Related to the issue of negotiating values above, projects can be convened to specifically address development of shared languages and hybrid methods and evaluation (or critique) metrics. At the same time, there is a burden on project members themselves to learn the values of funders, such as national institutes and foundations. Seed funding is crucial in bringing people together for conversations at high-risk first stages of work, with some such effort it is possible that exploratory projects could be supported under existing programs. Working on a white paper together and documenting the history of interdisciplinary problems could prove mutually-instructive. For example, often art proposals do not provide reusable citation structures and science proposals fail to provide self-critical reporting structures. These are basic components of the art and science cultures of knowing and should be both valued and deployed in everyday practice by collaborating disciplines in Arts + Sciences + Technology projects.

4. Best institutional practices for Science, Technology, Engineering, Art, and Mathematics (STEAM) learning

The acronym STEM is well-known, however this workshop supports the increasing usage of the acronym STEAM that entails integration of the arts in K-12 schools, colleges, universities, and lifelong learning. At the undergraduate level, the crucial questions revolve around potential conflicts between proficiency development and exposure to different disciplinary perspectives. At the doctoral level, a crucial issue is articulating the difference between research and art-practice, and which endeavors warrant the degree and funding to support progress toward it. Discussion of four outcome areas related to STEAM in institutes of higher learning follows:

Pedagogical approaches for STEAM

Practice and project-based learning have been agued as reinforcing the imagination and passion of students. Making robust artifacts is often underemphasized in the information sciences. Skill development and speculative artistic inquiry often work jointly to result in more productive student endeavors. Since many hybrid practices are recently emergent, there is some question as to whether approaches exist to teach them. The learning sciences need to be involved to help us to understand how to teach hybrid practices centered upon technologies that have only recently developed. Of course, all of this should start during K-12 education, and we must support endeavors that would prepare students for STEAM work in colleges and universities.

Academic programs that best foster hybrid practices

The information technologies at use during any time change rapidly, perhaps dramatically, even over the course of one student cohort's trajectory through a four-year university program. Given this rapid pace of change, educators must recognize students as inventors of culture. This behooves us to engage pedagogical approaches rooted in *critical literacies* perspectives supporting integration of students' indigenous knowledge into classroom experiences. Specific institutional practices supporting students as culture creators include using "equivalent experience" substitutions to avoid creating prerequisite driven silos and instituting intellectually-grounded policies for students to create self-designed degrees with strong faculty guidance.

Career aspirations and non-utilitarian intellectual/artistic aims

Often, in art discourses there is a sense that everything needs to be original, customized, and not (apparently) produced using off the shelf products. At the same time, there is sometimes a perception that practitioners embracing such ideologies are not employable. In fact, students with MFA degrees are often employable in the main industries of the creative innovation economy in the information technology sector. Animation companies, for example, seek effective storytellers and painters, not simply technicians. Interactive media companies that design products for large corporations seek design and human-centered computing students proficient in organizational structures, information architecture, and visual thinking skills. For many students, such eventualities are desirable. We should prepare students for many possible careers and avoid presenting dichotomous views that position the arts as outside of valued cultural practices and occupations. At the same time, students should be educated regarding the roles of the artists in society, not only pursuers of individualistic practices and industrial corporate gains.

Skill development and mentorship regarding career paths

Many students of today will have jobs that do not yet exist. However, educators still cultivate in students the ability to make decisions about their futures and ethical engagement with society. Hence, interdisciplinary programs must still result in development of core competencies. This enables students to understand that career pursuits are about enhancing quality of life not just about gaining entrance to "good" jobs. Instilling in students a sense of self-determination and leadership is important as a social phenomenon. We can teach them to be future leaders and employers and not just employees.

5. Significant trends in IT and creative practices

The most fertile ground: new forms of collaboration are emerging with youth communities. We should be interested in how these communities come together and what processes they use. Their characteristics include loose coupling between projects, participants, and intended accomplishments. At the same time, they feature emergent support structures such as strong motivation (activism and social engagement), with deep integration between work and play (games), inexpensive resources (software), and structures for sharing of assets and expertise (social media deployment and open source perspectives). We must also recognize that "youth" is not a catch-all category, diverse cultural communities of all ages create innovative collaborations often outside of academic settings. Such communities likely do not publish results in scientific journals and conferences, however, facilitation of opportunities for dialogue and discovery is crucial. We must also acknowledge that some technologies are more amenable to do-it-yourself (DIY) approaches than others.

Many other sharp observations were made to help situate the usefulness and challenges of technological trends. A growing number of people trained in software engineering and the arts are creating complex and resourceful hardware and software tools for use by arts and engineering students and professionals. Whereas, these communities have relied upon tools developed in the commercial sector in the past, this new tool development phenomenon has been a game changer in broadening access and participation. Businesses are beginning to recognize the value of encouraging communities of amateurs to test out new approaches, etc. Knowing how to use or develop technology does not equal knowing how to create new work. For example, it is common that undergraduate and graduate students who study electrical engineering and computer science lack the ability or self-efficacy to create new ideas and innovations that stretch beyond rote classroom exercises. This all points to the fact that the expert/academic vs. amateur/trend distinction needs redefinition. Understanding and harnessing trends is important in our data-laden societies.

Communication and networking technologies

"Open source," has become a trend phrase and is nothing new to mention here. However, open source-oriented communities reveal an important social trend: a shift to heterogeneous teams/ group problem solving. In such communities, identities are formed with an understanding that individuals each can perform multiple roles. This is often a contrast with industrial/closed systems. Ideas from open source ideology have also been reified in code recently. For example, crowd sourcing takes advantage of aggregate participation, often with a low barrier of entry, to enhance productivity. It is an open question how such approaches can be leveraged effectively for creative practices. However, it is evident that creative practitioners are eagerly active in open source communities and initiatives for software and hardware development.

Research of practice

Cognitive science addresses many creative practices, it may be useful to leverage this knowledge to better understand the nature of diverse practices and how individuals learn to participate in them. Theories of embodied cognition seem to be especially relevant, because they acknowledge the roles that artifacts play in thinking – a perspective quite aligned with artistic practices focused on creating objects using specific media. Such cognitive theories have suggested, for example, that allowing others to have a motor-sensory experience is better than verbal instruction. Cognitive scientists seek to explain how people and artifacts make meaning, exploring links between perception, action, and imagination.

Another approach is to consider computational artifacts as worthy of artistic investigation and humanistic study. We need to challenge the instrumental view that roots technology only as a means for pragmatic justification. Technologies such as the computer become media, as are clay, paint, or, in their own rights. When we view the computer as a medium, data structures and algorithms are worthy of introspective consideration and study as cultural artifacts.

Specific Trends

Two trend phrases emerged: DIY movements and citizen scientists. Although relatively few people are capable of creating complex tools and software, users of commercial software often create complex cultural practices and new applications. This could be leveraged against another trend, declining enrollments in computer science programs over the past decade. Recognizing the importance of indigenous and creative technological practices outside of academic is mutually beneficial. These practices can be supported through democratization by supporting easier access and ease in *creating* tools and software applications – not only using them.

Creativity theories, methods, practices

Theories of creativity are not only to be found in cognitive science. Artistic disciplines provide necessary insights regarding ways that the notion of creativity itself is contested. There is intense debate about what is the essence of creativity and with which methods to understand, analyze and exploit the concept of creativity. Indeed, many wonder whether it is useful or possible to develop a theory of creativity at all. This suggests that "creativity" might not be the term around which Arts + Sciences +

Technology projects should be evaluated – though creativity is certainly a characteristic of such endeavors.

6. Opportunities to develop institutional networks across disciplines

A major issue in the development of networks across disciplines is the development of individuals capable of performing effectively in such networks. One point raised is that cultivating maximal expertise in multiple areas by all project members may be an impossible, even if desirable, aim.

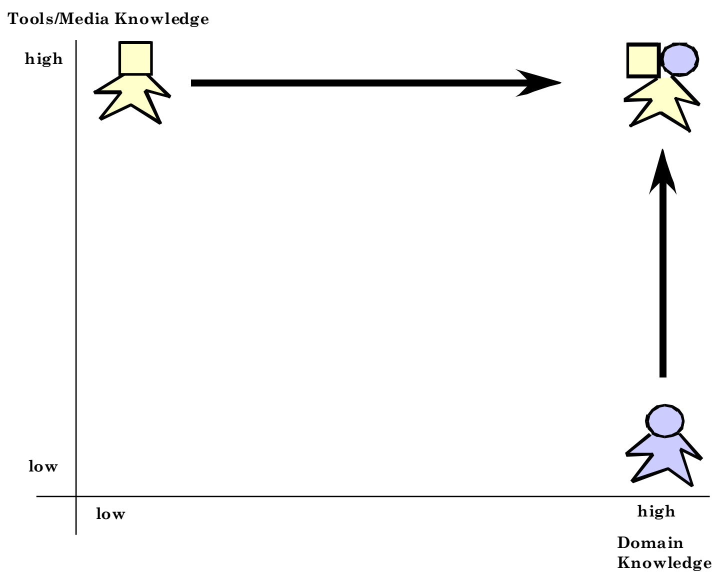

Figure 1: Desired but Unrealistic: "Superhuman" (software and domain expert)[1]

Rather, it may be more realistic to cultivate and expect sub-expertise by collaborating members.

[1] G. Fischer, H. Eden, and H. Dick. Lecture: "Transdisciplinary Education and Collaboration." University of Colorado, Boulder, December 10, 2010.

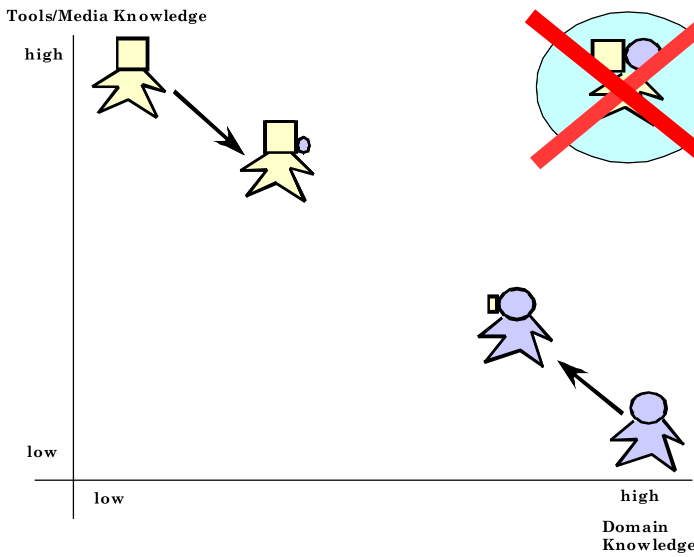

Figure 2: Realistic: Learning "something" about the Other Domain[2]

It may, however, be the case that institutional relationships must be developed at the same time as individuals are cultivated who can take full advantage of such networks. Establishment of strong institutional networks can help to facilitate and advance our communities of interest in art + science + technology in establishing more robust collaborations. Four areas were examined in relationship to the aim of institutional networking.

Role of networks in interdisciplinary methods
We can effect change in networks/larger agencies through organizing around a particular problem or forming a community of interest. This should be expanded to curatorial (e.g., museums and galleries), non-profit, and industrial contexts.

Communities of interest
Building upon participant Gerhard Fischer's observations and diagrams above, multiple interests of community members can be leveraged into cultivation of multiple areas of expertise. The end result is the communities of interest can be developed into communities of practice. Such communities may be able to operate and network more effectively and efficiently.

[2] ibid.

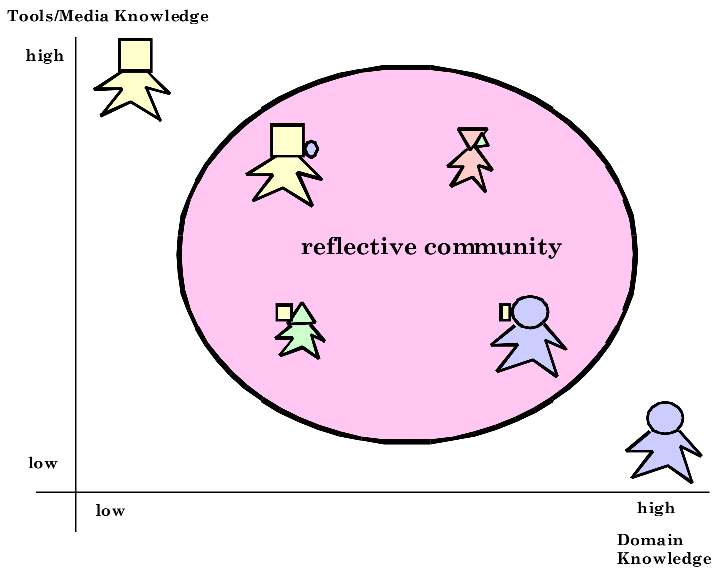

Figure 3: Objective: Reflective Communities[3]

International collaborations

Specific models for international collaboration where highlighted, such as the Synapse Initiative through the Australian Arts Council (www.synapse.net.au), and the GRAND (Graphics, Animation and New Media) Network Centre of Excellence in Canada (www.grand-nce.ca). Most recommendations were more general. The roles of international festivals and conferences were highlighted as well as increased opportunities for grant funding of such endeavors was advocated. Additionally, national academic and non-profit institutions should increase opportunities for international exchange across institutions and disciplines. "Artist-in-Lab" and "Scientist-in-Studio" visiting residency programs where discussed as an actionable example.

Strategies for transforming cultures

Identified strategies for transforming institutional cultures were also broad. Key suggestions include working with grassroots and non-traditional organizations, reducing barriers to access through broadening participation and inculcating diverse disciplinary values and areas of expertise, and visionary leadership. Several participants rallied around the need for new manifestos that support not only desire for change, but action toward change.

Section 7. Big Questions

At the start of the workshop, participants were asked to describe what they saw as the *Big Question* in Arts + Sciences + Technology research and collaboration. These

[3] ibid.

questions are summarized below in seven emergent clusters. These questions provide a reflective precursor to the concluding remarks in Section 9 below.

Workforce/Education/Social Good related

- How can we tap into the passions of today's youth to provide them with 21st century skills and employment?
- What is the role of the arts in complex issues like climate change?
- How can the arts and humanities work in service of solving larger problems?

Disciplinary/Interdisciplinary Collaboration related

- Ontological differences bedevil our two fields/disciplines. How can the cognitive sciences be applied to rethinking art/aesthetics?
- How do we tease out/identify fundamental assumptions within the disciplines?
- What is the meaning of creativity in different discipline contexts?

Disciplinary/Interdisciplinary Discourse Related

- How can we encourage cultural translation of skills between different communities working on similar problems?
- How do we frame knowledge discovery as both interpretive art and science when the fields do not speak the same language?
- What is the value of art in a broader cultural sense? Science and technology does a better job of this and gets funding, whereas art is still often framed as a romantic endeavor. We need to articulate the formative aspects that art has on society as a whole. Can we place best practices on the table for examination?
- How much progress have we made in cross-disciplinary education?

Financially related

- How can collaborations foster vitality when they are financially starved?
- How can arts funders change their structure to better support changing fields?

Institutional/Infrastructure/Scaling related

- How can the structures of arts and sciences organizations and educational institutions enable art/science learning?
- What computational systems allow for research and artwork that is considered "real" by both areas?
- How can we break down silos in university curriculums to foster these kinds of art/science collaborations?
- The system of rewards in academia is not conducive to collaboration and can be punitive. How can funding agencies help solve this problem – noting that any single institution cannot do this alone?

Measurement related

- In engineering and art, how do you know that your invention works?
- How can these interdisciplinary projects be evaluated?
- How do we measure the social value of their work?
- What new ways of evaluation can be developed for projects with long-term impact? Can ecology be a foundation for this effort?
- Art making has outcomes, but they are not always measurable in the same way as scientific research. Does collaboration have to result in evaluable products?
- Accidents and discovery – how can we incorporate these?

Culture related

- How do we better understand computational art that better resonates in the larger culture?
- How does computing come together with culture?

8. Action Opportunities and Volunteer Leaders

As one of the concluding activities of the workshop, concrete action opportunities with a five-year horizon were identified. These action opportunities should not be interpreted as recommendations, much less as mandates, rather they reflect the directed energy of the thought leaders convened, and hence represent collective expert wisdom in the area of Arts + Sciences + Technology collaboration. The following chart groups action opportunities into types oriented toward national institutes, community-building and networking, education and academia, and dissemination endeavors.

Opportunity	Challenge	Action
ACTION TYPE: National Institutions		
Fund Interdisciplinary Projects in Arts + Sciences + Technology	Long-term funding initiatives are needed to maintain U.S. competitiveness in the international Art + Science + Technology research arena.	• Inter-agency crosscutting initiatives. • Multi-staged project support. • Faculty exchange programs. • Research experiences for non-STEM students. • Travel grants for festivals and conferences. • Academic and non-profit partnerships. • Scientist-in-Studio and Artist-in-Labs programs.
Demonstrate and Evaluate Impact	Demonstrating impact of Arts + Sciences + Technology research is difficult as research archives across disciplines are not linked.	• Build a repository for citation and archiving research in the field to study the history and support the future of the field.

Evaluate Evaluation Metrics	There are real and perceived differences in how fields in the Arts, Sciences and Technology validate what they value.	Create frameworks and forums for sharing, discussing and understanding the differences and similarities across cultures of knowing in the arts, sciences, and technology. This includes articulating ways to resolve differences between review metrics made by differing funding agencies.
ACTION TYPE: Building Networks		
Form a Blue Ribbon Panel to Articulate Importance of this Area	It is time for the next edition of "Beyond Productivity: Information, Technology, Innovation, and Creativity" report published by the National Academies Press (2003), that examines progresses in the field that have been made and continued roadblocks.	• The blue ribbon panel should include major artists, museum curators, and scientists with NEA, NEH, and other science and education federal funding agencies. • Build an argument for the inclusion of Art + Science + Technology research activities and supporting institutions in the Networking and Information Technology Research and Development (NITRD) program, appropriate working groups and reports as well as the President's Council of Advisors on Science and Technology (PCAST).
Establish Networks of Excellence Across Institution Stakeholders	Art + Science + Technology networks in the United States tend to be part of academic institution systems. They can be vibrant, yet closed to those outside of those systems.	• Connect a distributed community of stakeholders. • Inform the community and others about the impact of the field on national STEM education initiatives. • Promote diversity of perspectives, approaches and people in the creative innovation economy. • Forge partnerships between international, federal, state, and local arts, research and industry institutions. • Implement interdisciplinary hubs for constituents in the field to encourage dialogue. • Build collaborative tools for maintaining online communities.
ACTION TYPE: Education and Academic Institution Policy		
Identify Pedagogical Outcomes for STEAM Learning	There has been enrollment decline in Computer Science programs as programs that integrate computational thinking and the Arts are increasing. We must devise metrics to identify core competencies in these new pedagogies as they relate to strengthening education in the United States.	• Align Art + Science + Technology pedagogies with 21st century learning skills. • Scaffold skills needed for engaging STEM and the Arts from PK-12 to lifelong learning. • Reward creativity, curiosity and problem solving with tolerance for alternative points-of-view. • Benchmark best practices that create critical thinkers and leaders for the ever changing job market. • Establish a framework for identifying artistic skills valuable to the sciences and

		engineering and vice versa.
Adapt and Adopt Academic Institutional Policies that Promote and Reward Art + Science + Technology Research and Practice	Silos and unleveled playing fields create disparities in resources, infrastructure, and required teaching to research ratios between and across disciplines.	• Write mission statements that promote interdisciplinary pedagogy as a first principle. • Resolve silo mentality with sustained dialogues across the institution. • Establish tenure review guidelines that reward experimental collaboration and shared student resources across disciplines. • Collaborate with non-profit institutions to the benefit of all. • Establish best practices guidelines for hiring and promoting faculty with joint appointments. • Due diligence: Look to the College Art Association, Association for Computer Machinery, Computer Research Association and other national groups for guidelines that can be adopted and adapted.

9. Conclusion

In Arts + Sciences + Technology collaborations and interdisciplinary work, a heroic and necessary step is making our values explicit. It allows us to critically look at our own endeavors and provides the necessary distance for envisioning how it can be integrated with the work of others. With our values articulated, it is not enough to pose questions, rigorous follow-through is crucial. Yet, we are not always sole determiners of our research and creative practice destinations. Often new enablers are outside peer review groups. In order to communicate with many of these groups, evaluation is key providing the institutional justification for commitment of resources. Hence, we must simultaneously work to expand the intellectual grounding for interdisciplinary forms of evaluation, at the same time as we remain open to engaging in evaluation methods that may be outside the purview of our respective disciplines.

Ideally, there should exist many programs for supporting interdisciplinary efforts based in equity across disciplines. Yet, the reality is that many of the thought leaders who attended this workshop have participated in institutions from the margins. Through coalition building endeavors such as this workshop we can jointly define a collaborative future bridging arts, science, and technology fields.

About the Workshop Storymap

The workshop Storymap is a graphic depiction of the key workshop discussion points.

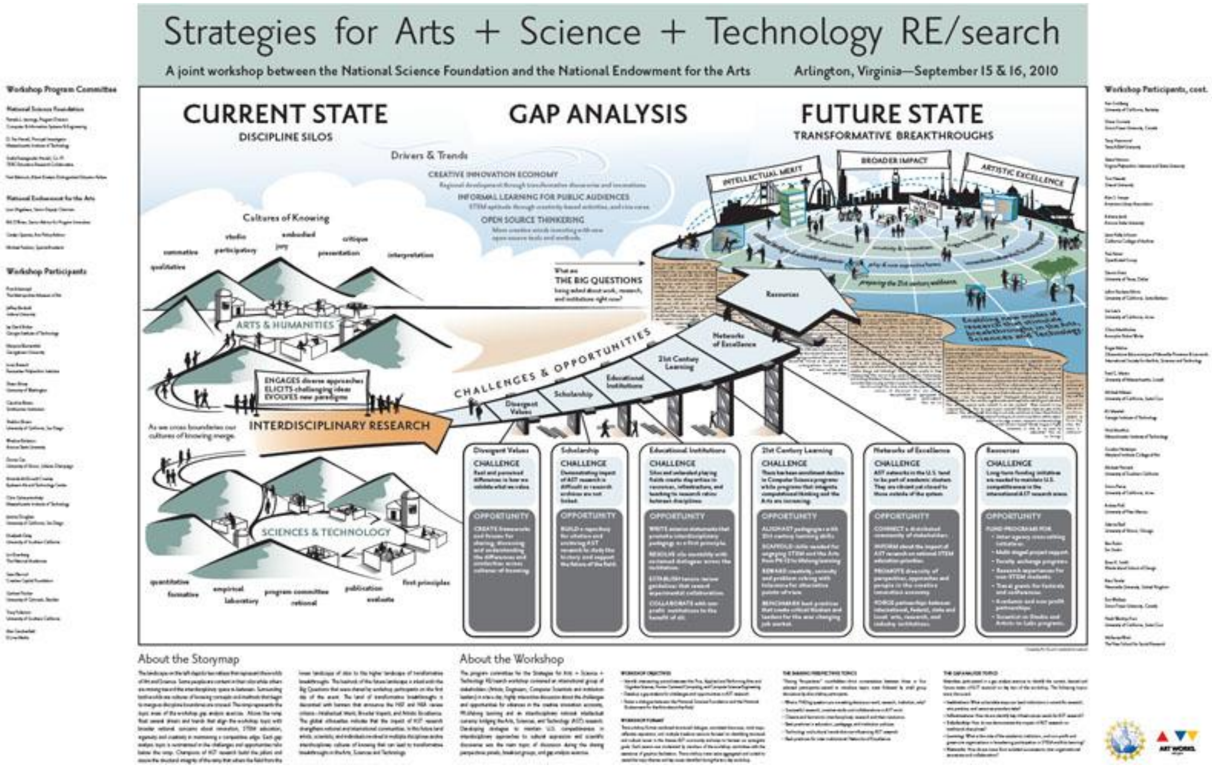

Figure 4: The Workshop Storymap

In the Storymap, the landscape on the left depicts two valleys that represent the worlds of Art and Science. Some of the people are content in their silos while others are moving toward the interdisciplinary space in-between. Surrounding both worlds are cultures of knowing concepts and methods that begin to merge as discipline boundaries are crossed. The ramp represents the topic areas of the workshop gap analysis exercise. Above the ramp float several drivers and trends that align the workshop topic with broader national concerns about innovation, STEM education, ingenuity and creativity in maintaining a competitive edge. Each gap analysis topic is summarized in the challenges and opportunities tabs below the ramp. Champions of AST research build the pillars and assure the structural integrity of the ramp that ushers the field from the lower landscape of silos to the higher landscape of transformative breakthroughs. The bedrock of the future landscape is inlayed with the Big Questions that were shared by workshop participants on the first day of the event. The land of transformative breakthroughs is decorated with banners that announce the NSF and NEA review criteria—Intellectual Merit; Broader Impact; and Artistic Excellence. The global silhouettes indicate that the impact of AST research strengthens national and international communities. In this future land people who are working in interdisciplinary settings among new and revised cultures of knowing that lead to transformative breakthroughs.

PDF copies of the Storymap are available from the following workshop program committee members: Fox Harrell (fox.harrell@mit.edu); Pamela Jennings (jennings@nsf.gov); and Bill O'Brien (obrienb@arts.gov).

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