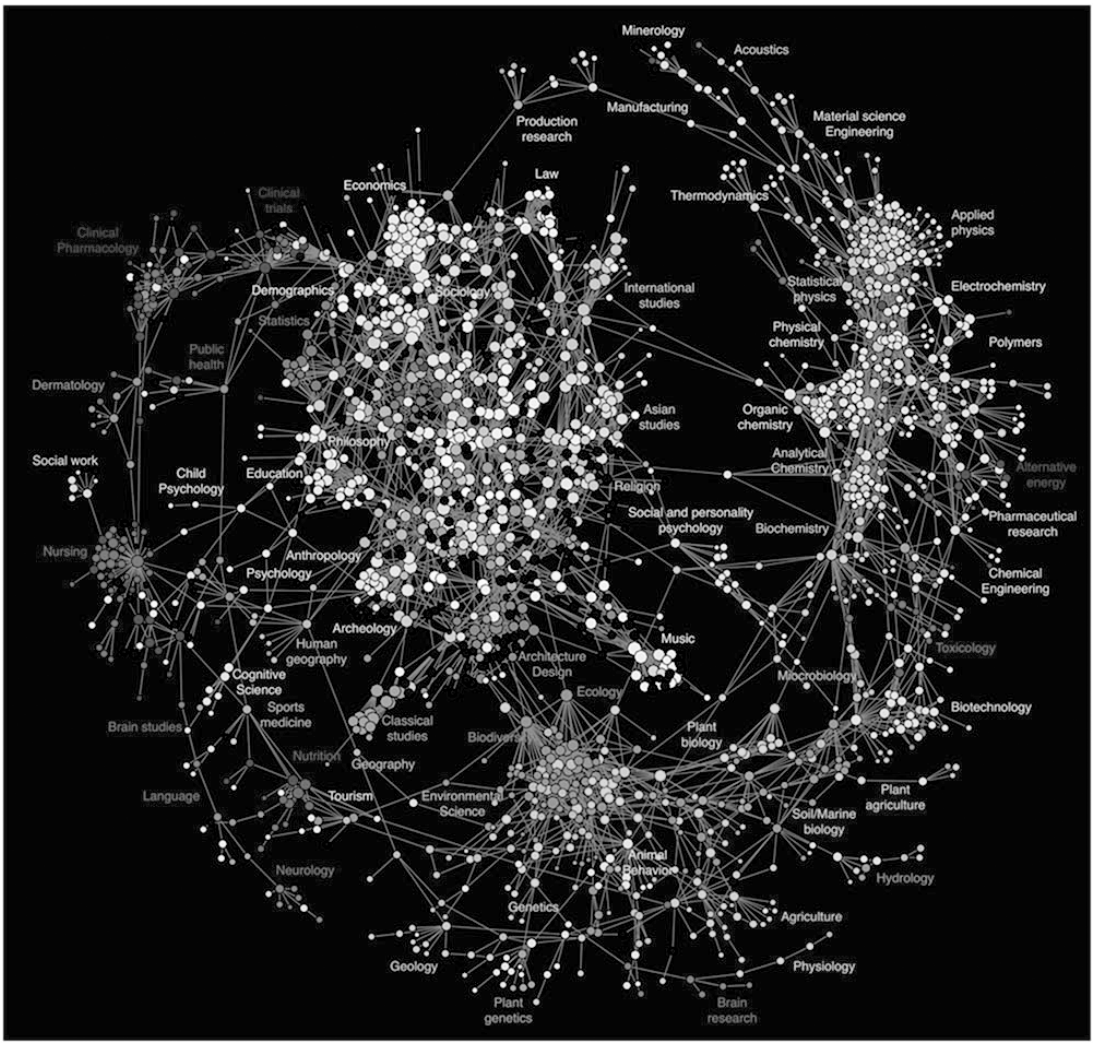
Steps to an Ecology of Networked Knowledge and Innovation

Enabling new forms of collaboration among sciences, engineering, arts, and design



VOLUME I: Synthesis report

Prepared by Roger F. Malina, Carol Strohecker, Carol LaFayette, and Amy Ione
on behalf of the SEAD Network White Papers Steering Group and 200 White Papers contributors

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Cover image: Map of science derived from clickstream data (2009). Maps of science resulting from large-scale clickstream data provide a detailed, contemporary view of scientific activity and correct the underrepresentation of the social sciences and humanities that is commonly found in citation data. *Originally published in Bollen J, Van de Sompel H, Hagberg A, Bettencourt L, Chute R, et al. (2009) Clickstream Data Yields High-Resolution Maps of Science. PLoS ONE 4(3):e4803. doi:10.1371/journal.pone.0004803*

Steps to an Ecology of Networked Knowledge and Innovation: Enabling new forms of collaboration among sciences, engineering, arts, and design

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EXECUTIVE SUMMARY

Successful collaboration among scientists, engineers, artists, designers, and humanities researchers has been accelerating over the past decade. This has generated emerging practices that impact work and have potential to mitigate the difficult problems of our times. The innovations emerging from the intersection of the sciences, engineering, arts, and design are transforming our economic, cultural, and learning contexts.

During the past few years, US agencies, including the National Science Foundation (NSF), the National Endowment for the Arts (NEA), and the National Endowment for the Humanities (NEH), have sponsored workshops convening this community. The initiatives resulted in NSF grants that spawned the sciences, engineering, arts, and design (SEAD) network, the XSEAD portal, and this study.

The SEAD network includes professionals and students in the physical, life, and social sciences; mathematics, engineering, and technology; the creative arts in all their forms; designers of all kinds; and researchers across the humanities. An open-access website (http://sead.viz.tamu.edu/) serves the community and includes these statements of purpose, focusing on advocacy in the following four areas:

Culture and economic development.

Research and creative work.

Learning and education.

Collaboration and partnership.

The SEAD White Papers initiative was chaired by Roger Malina and cochaired by Carol Strohecker, with the assistance of an international Steering Group and coordination by Carol LaFayette and Amy Ione. Through an open call, we asked the community what obstacles and opportunities they encounter and what related actions they would suggest. We received an impressive and generous response: 73 abstracts, 55 full White Papers, 4 detailed Meta-analyses, and 260 Suggested Actions. More than 150 individuals were involved, freely contributing their experience and ideas in an open-access mode of knowledge sharing.

We compiled a bibliography of more than 40 prior reports whose aims and objectives overlap or connect to those of this effort. The SEAD White Papers initiative grows from and builds on that extensive prior work. However, we note that there has been only partial implementation of many of the recommendations already put forward in recent years, in many countries.

What is new in 2013 is the increasing size of the SEAD research and creative community, the accelerating effects of the technologies for networked communication and collaboration, the impressive successes in recent years, and the urgency of many of the issues in the face of societal, economic, and cultural concerns. There has also been renewed interest in how the arts, design, and humanities can contribute to STEM (Science, Technology, Engineering, and Mathematics) educational initiatives, sometimes known as "STEM to STEAM."

The metaphor we have chosen to adopt, of an ecology of networked knowledge and innovation, seems pertinent to the new situation. The SEAD White Papers report is structured around action clusters that group the Suggested Actions that authors identified as key to implementing SEAD practices. These clusters frame questions, or processes, that specific stakeholders can use as entry points for consideration of interventions, many of which inevitably would be long-term. Typically the action clusters pertain to the interests of multiple stakeholders, requiring the interplay of public and private actors and organizations. Eleven categories emerged, within which we identified 13 action clusters as key processes:

TRANSLATING: Problem-driven connections among academic, commercial, and civil societies

1. Project formation and translational value

CONVENING: Overcoming transdisciplinary thresholds

2. Conferences, workshops, camps

ENABLING: Sustaining balanced SEAD relationships

3. Forming safe, productive environments for hybrid individuals and practices

INCLUDING: Spurring innovation through diversity

4. Communities addressing global issues and local solutions

EMBEDDING: Public engagement and negotiation

5. Outreach, "citizen science," dissemination

SITUATING: An emerging ecology of creative places

6. "Alt spaces"

SENSE-MAKING: Multimodal knowledge and ways of knowing

7. Integrating understandings through the SEAD perspectives

DOCUMENTING: Recording and transmitting

8. Capturing, publishing, curating, archiving

LEARNING: Tapping into the passion and creativity of lifelong curiosity

9. Sharing blended experiences

COLLABORATING: Methodologies working across discipline and institutions

10. Collaborations between individuals and disciplines
11. Partnering across organizational boundaries

THRIVING: SEAD ingredients as essential contributors to healthy communities

12. Ethics and values
13. Well being and joyfulness

As a final Suggested Action, a consensus emerged among the study participants that the time is right to conduct a new formal study, to assess more comprehensively the emerging SEAD research area of research and practice and opportunities it may present for specific contributions to national agendas.

REPORT SYNTHESIS

Several of the participants in the SEAD initiative[1] decided to prepare a preliminary report based on broad community consultation, to be delivered to NSF as one of the outcomes of the SEAD Network grant. Our surmise was that such a preliminary study might identify the timely need for a new formal, national-scale report in the United States, *Beyond Productivity II*. As was true of the original *Beyond Productivity* (Mitchell, Inouye, and Blumenthal 2003), we are concerned with intersections of computing with the humanities, arts, and design—that the original authors dub Information Technology and Creative Practices (ITCP). But we are also concerned more broadly with mutual benefits for a broad spectrum of sciences and mathematics engaging with creative practices and the humanities. We have settled on the SEAD moniker to signify the broad range of disciplines and to characterize homophonically the actions we hope to germinate. The overarching theme becomes collaboration, as transdisciplinary interests and practices continue to grow and as public discourse increasingly acknowledges the complexity of today's global issues and the need for multiple kinds of expertise in addressing them.

Because the SEAD community works internationally and is heavily socially networked, contributors to the White Papers hail from around the world. We asked the community what obstacles and opportunities they encounter and what related actions they would suggest. We received an impressive and generous response: 73 abstracts, 55 full White Papers, four detailed meta-analyses, and 260 Suggested Actions. More than 150 individuals were involved, freely contributing their experience and ideas in an open access mode of knowledge sharing.

We have also compiled a bibliography of more than 40 prior reports[2] whose aims and objectives overlap or connect to those of this report. We are struck by the careful prior work and the only partial implementation of many of the recommendations already put forward in recent years. Many of the Suggested Actions proposed in the SEAD White Papers are identical or build upon those already presented previously by members of the SEAD and related communities of practice. The SEAD community of practice is a truly networked knowledge community that overlaps and connects with other communities of

[1] More information about SEAD and SEAD's goals are available at http://sead.viz.tamu.edu/
[2] The prior reports are listed in Appendix 5 and are available at http://seadnetwork.wordpress.com/reports/.

practice; it is evolving over time and is not defined through a disciplinary corpus, but rather is outcomes-focused.

A number of new areas, however, are identified as opportunities potentially served by large communities of research and practice that are larger and/or stronger than at the times of prior reports.

What is new is the growing size of the research and creative community, the accelerating effects of the technologies for networked communication and collaboration, the notable successes in recent years, and the urgency of many of the issues in the face of societal, economic, and cultural concerns. Recently there has also been renewed interest in how the arts, design, and humanities can contribute to STEM (Science, Technology, Engineering, and Mathematics) initiatives, a trend sometimes referred to as "STEM to STEAM."

As we began to synthesize our conclusions, it seemed that rather than reiterating specific suggestions already issued by many previous reports, we would structure this document around action clusters that evolved from a critical mass of the White Papers' comments and suggestions. Accordingly, we have grouped the Suggested Actions into 13 clusters. Each of these requires in-depth explication and strategies, which are elaborated in the pages that follow.

These action clusters may frame questions that specific stakeholders can use as entry points for longer-term consideration or interventions. Many of the action clusters pertain to the interests of multiple stakeholders, requiring the interplay of public and private actors and organizations.

Action Clusters Overview

TRANSLATING: Problem-driven connections among academic, commercial, and civil societies

1. Project formation and translational value

CONVENING: Overcoming transdisciplinary thresholds

2. Conferences, workshops, camps

ENABLING: Sustaining balanced SEAD relationships

3. Forming safe, productive environments for hybrid individuals and practices

INCLUDING: Spurring innovation through diversity

4. Communities addressing global issues and local solutions

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5. Outreach, "citizen science," dissemination

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9. Sharing blended experiences

COLLABORATING: Methodologies working across discipline and institutions

10. Collaborations between individuals and disciplines
11. Partnering across organizational boundaries

THRIVING: SEAD ingredients as essential contributors to healthy communities

12. Ethics and values
13. Well being and joyfulness

The Suggested Actions presented in the White Papers, together with the action cluster framework, relate to our four framing objectives: culture and economic development, research and creative work, learning and education, and partnership and collaboration. Stakeholders can use this very rich set of specific Suggested Actions to develop strategies for enabling SEAD activities. A compilation of the Suggested Actions is listed in Appendix 1 of this report.[3]

For comparison with the 13 action clusters, the *Beyond Productivity* (Mitchell, Inouye, and Blumenthal 2003) report proposed multilevel strategies around six targeted areas:

[3] As noted above, many of these Suggested Actions appear in prior reports, which are listed in Appendix 5.

1. Providing new tools and media for artists and designers;
2. Providing opportunities to develop ITCP skills;
3. Creating environments that support ITCP;
4. Fostering the culture of information technology and creative practices;
5. A new form of research;
6. Making ITCP happen.

A comparison of that report and the outcomes of this SEAD White Papers study motivates a final overarching Suggested Action or "Call to Action": we conclude that it is opportune to reconvene a national study, nearly 15 years after the *Beyond Productivity* report was initiated, with the scope of a new report emphasizing:

1. The expansion of the SEAD community of practice from IT-centric preoccupations to other disciplines of science and engineering, but also humanities and design;
2. The growing international cross-coupling of SEAD groups and consortia;
3. A focus on societal and economic issues.

Action Clusters and SEAD Goals

TRANSLATING: Problem-driven connections among academic, commercial, and civil societies

1. Project formation and translational value

Working across traditional boundaries of organizations, disciplines, and sectors is increasingly recognized as a strategy for innovation. Authors suggest concerted action among engineers, industry members, and philanthropists to identify projects with potential commercial value and to promote collaboration toward realization and distribution of results. Benefits may be social and/or economic. SEAD collaborations leading to product development have included ventures in augmented reality, high-end 3D animation, and wearable technologies.

One example is the original creation of two new Chinese fonts, which resulted from a collaboration between a university researcher in the arts and an electronics company.

"E-agriculture" has become a prominent area of application for these tools, benefiting particularly from collaborative development of mobile phone apps that can provide information and communication capabilities out in the field. The general usefulness of mobile communication devices has led to requests for the mobile device industry to develop means for open and free content creation that can be readily exchanged across platforms.

Some authors note a strategy for facilitating transdisciplinary collaboration that considers elements common to multiple disciplines. For example, pattern, rhythm, fractal-like structures, and hierarchies can be found in content related to the sciences, engineering, arts, and design; focusing on these common concepts can facilitate translating to or from different application areas. Similarly, natural structures and cyclic properties are present in many in real-world problems; focusing on these concepts could help in communicating toward development of transdisciplinary teams and education about a broad range of topics.

Authors assert that an authentic inquiry mode of learning demands a fundamental restructuring of the school classroom in terms of its organization, teacher-student ratio, processes, time allotment, activities, resources, and tool use. A reconceptualization of the roles of teacher and student is also needed. New approaches would require design and development of new pedagogical activities and materials for teaching and learning. Teachers would need relevant professional development and empowerment. Evaluations are also needed of both the effectiveness of new teaching-learning strategies and methods for their implementation in the classroom.

Some authors say that encouraging students to explicitly consider the transferability of their knowledge can help leverage skills learned in one domain toward understanding in another. Observation and working with patterns, for example, are two skill sets that are relevant in domains of both art and science and thus worth emphasizing in curriculums and in self-reflection on learning. Making explicit how noted polymaths applied skills and transferred knowledge across domains could also promote students' innovative thinking. Aside from conceptual bridging, careful uses of technologies could facilitate learning across domains. Some say that the potentials of mobile technologies for knowledge dissemination and engagement continue to be largely unrealized.

Several authors address pragmatic concerns that may arise as members of different disciplines attempt to collaborate. The same underlying commonalities that can facilitate

translations across disciplines could pose deceptively simplistic views of others' disciplines or of how to work together. Authors repeatedly note the importance for collaborators to learn the content and methods of their partners' domains. The same applies to art critics and other evaluators of results from transdisciplinary collaborations.

Collaborators' commitments to ongoing, cross-cutting learning is necessary to build trust and ensure the quality of results in terms of both depth and breadth, beyond obvious SEAD areas such as scientific illustration and education. Artists could lose interest if the collaborations are framed only in terms of communicating science. Scientists need to understand that visualizations, lab specimens, and models need to be translated as artistic works in order to become appropriate for display in galleries and other artistic contexts.

Authors express the hope that scientists and engineers will concentrate more on inventing innovative technologies that could aid cultural and societal development in emerging countries. Many authors also note the importance of forming partnerships with industry at the outset of a project or as early as possible, in order to include "real-world" perspectives and increase the likelihood of translating results for broader societal benefit. Authors encourage SEAD practitioners to broaden and diversify their own networks, rather than placing the burden of trust-building on a collaboration among strangers. They also recommend that funders underwrite interdisciplinary research in all phases of their decision-making processes. An underlying consideration is the importance of maintaining records of transdisciplinary collaborations and their outcomes.

Many of the White Papers emphasize the need to create collaborations that do not seek to merge disciplines, but rather to create agile and evolving cross-connections among disciplines. Techniques from "translation studies" within the humanities may be of interest: the field of translation studies has evolved beyond linguistic translation to cross-cultural, cross-media and cross-discipline translation.

Despite the growing visibility of successful collaborations and translations of SEAD work, many people still need to be convinced of the value of working across disciplines. Some authors suggest that members of scientific communities may more readily accept the premise if presented with rigorous evidence of theoretical or experimental benefits.

Just as in medical research it has been necessary to establish targeted "translational medicine" approaches to transfer research results into societal use, so it is the case for SEAD. Translating SEAD innovation into societal use requires deploying a variety of

devices in collaboration; partnering; investing in alternative spaces, accelerator and incubator strategies; multi-outcome funding, and organization. Given the rapidly changing, networked organization and collaboration structures, a specific emphasis on "translational SEAD" seems warranted.

See Appendix 1 for a listing of specific Suggested Actions from the White Papers pertinent to this action cluster.

CONVENING: Overcoming transdisciplinary thresholds

2. Conferences, workshops, camps

This set of actions proposes convening a series of conferences or symposia to pursue dialogue about timely topics, facilitate scouting for collaborative partners, and engage funders in considering the merits and potentials of specific SEAD-related interest areas. Calls for an exchange of ideas on certain topics recur throughout the papers. Among these "hot topics" are STEAM learning, MOOCs (massive open online courses), environmental sciences and ecology, complexity and artworks to explicate it, and how to more fully engage scientists in SEAD initiatives.

Several papers underscore the benefits of connecting artists and scientists with local communities. Authors suggest creation of forums for mixing people from business, academic, and nonprofit organizations. The venues might include public events and large-scale displays that invite participation by community members and require different kinds of skills to realize and engage. Podcasts are another possibility, as are forums that explicitly encourage discussion and networking, such as live webcasts and other web-based forums, and "art-science cafes" for physical gatherings. Suggested exchanges vary in formality, from happenstance interactions to roundtable discussions and organized meetings and seminars. One author poses a game-like "appropriation logic" in which participants—whether scientist, engineer, artist, designer, funder, or other—could propose a project so others could then "rephrase" it to begin an exchange. Not surprisingly, the papers repeatedly emphasize involving potential funders along with members of industry, government, and chambers of commerce, as well as researchers and other collaborators on transdisciplinary projects.

Some authors suggest forming a consortium of universities and art schools in an ambitious, transdisciplinary collaboration to compile art, science, and technology work, and evaluations of such work, during the past 20 years. The results of this scholarly effort would be presented through a visual map providing an overview of SEAD foundations.

Another method for this study could be to convene a broadly representational symposium in which discussion of the works is considered as an art form or "text" in and of itself.

Topics suggested for other conferences and online repositories include the central nervous system as a model for modular architecture communication protocols among complex software systems; form and functionality of the human body to inspire collaborative work; synthetic characters as a mode for developing artificially intelligent systems; environmental cleanups and other convenings that call attention to underlying patterns or rhythms in the natural world, to then become conceptual bases for creative work; topics more generally in biology and life sciences, the physical sciences, and social sciences; and the ways in which a diverse data visualization community could help to address the problems of big data. Authors also suggest that public receptivity to scientific topics could become a gauge for prioritizing funds for research. The workings of transdisciplinary teams, authors note, also warrant further study.

Another particular suggestion is for multi-modal, inquiry-based learning programs to arise out of targeted collaboration among brain scientists and educational researchers. Another appeal is for the creation of focus groups, roundtable discussions, and conferences that include members of the fields of dance, choreography, cognitive science, and neuroscience. Another call is for studies of complexity to be incorporated into high-school curriculums, as well as introductions to the history and philosophy of science.

More generally, authors call for the compilation of a "knowledge bank" of "emergent learning" courses and curriculums focusing on unpredictability rather than best practices, and on constraints rather than outcomes. Currently, blended learning approaches that build upon MOOCs are appearing. These courses and events are contributing to the development of SEAD-related curriculums. Discussions among the participants in these online forums and their extensions into associated "real world" cultures, could become a rich source for beginning a practitioner- and designer-generated taxonomy to facilitate studies of the milieu and help promote its advancement. Authors suggest that curriculums should span multiple grade levels and that curriculum development should not be confined to small districts, but draw on global resources. Some authors suggest choosing Arduino, Kinect, and Internet technology platforms rather than textbooks. Others would like to see residency programs in community-based wet labs and hacker spaces treated on a par with university artist-in residence and scientist-in-residence programs, perhaps even as career requirements.

Authors point out that individuals entering collaborative relationships need to maintain an open-mindedness that allows for ongoing adjustments of preconceptions about partners' disciplines. Likewise, educating one's collaborator must be ongoing. Productive transdisciplinary collaboration also requires a supportive infrastructure. Residency programs need to be served by appropriate facilities such as black boxes, workshops, or dedicated lab spaces. Private housing for families would be an important source of support for SEAD experimenters. New academic journals, reduced teaching loads, and grants for nontenured faculty, individuals, and community nonprofit organizations could also encourage transdisciplinary collaborations.

To promote innovation, companies could allow time for employees to participate with members of other organizations in transdisciplinary projects. Formal links among organizations could support meetings and forums on cross-disciplinary communication, toward development of a common language leading to lasting, productive relationships. A common language based on pattern and rhythm, for example, could connect seemingly unrelated viewpoints and yield transformational insights or perceptual shifts in SEAD areas. Data visualization is increasingly important, yet current methods for working with data are diffuse and do not benefit sufficiently from cross-disciplinary knowledge exchange. Platforms such as conferences, workshops, and online open repositories for sharing visual strategies, algorithms, and other methods would be helpful in bringing forward this increasingly needed vernacular.

We have called out a specific "Convening" action cluster because the nature of the SEAD community of practice requires new approaches. We surveyed SEAD network contributors for the conferences they regularly attended and found a heterogeneous list of 67 different conferences, ranging from those focused in science, engineering, mathematics, education, arts and humanities as well as a few interdisciplinary venues such as the Society for Literature, Science and the Arts and a growing number of visualization conferences internationally (See Appendix 7). The workshops convened by the NSF, NEA and NEH leading up to this White Papers study gathered professionals who had never met even though they had overlapping research and teaching practices. It will be the nature of SEAD practice that it will not consolidate into typical disciplinary practice methodologies, with dedicated conferences, but rather requires an evolving and reactive landscape of convenings in a variety of forms, some within existing conference venues, others in ad hoc formats.

See Appendix 1 for a listing of specific Suggested Actions from the White Papers pertinent to this action cluster.

ENABLING: **Sustaining balanced SEAD relationships**

3. Forming safe, productive environments for hybrid individuals and practices

A recurring issue in many of our White Papers is the difficulties and obstacles often faced in SEAD practice because of "asymmetries"—the differing personal and institutional environments faced by collaborators from different disciplines. These issues were also raised in *Beyond Productivity* (Mitchell, Inouye, and Blumenthal 2003); if anything, the situation has become more complex. These issues are raised in a number of the other action clusters that we have identified; for instance the Situating action cluster is concerned directly with the issue of designing workspace environments that allow the various actors to participate.

Interdisciplinary practices within the sciences (e.g., biophysics,) or between science and engineering (e.g. bioinformatics), or in integrative studies (environmental sciences) occur within a shared episteme of the scientific method. Many sciences can be described as technosciences (for example, genomics or many subdisciplines of astrophysics such as gravity wave astronomy) because their scientific agendas are so heavily coupled to technological ones. These connections facilitate cross-disciplinary work, and the Information Technology focus of *Beyond Productivity* foregrounded such shared connections, for example, through shared tool development. The expansion from an IT-centric focus to include the broad ranges of physical and life sciences, as well as the disciplines of design and humanities, complicate significantly the required approaches.

The demands of such interdisciplinary work, including differing heterogeneous loci of practice and epistemic methodologies, create very strong asymmetries that entail particular levels of risk and possible conflict. (The current stresses in the humanities due to the emergence of the digital humanities are emblematic). A number of White Papers report on SEAD collaboration failure because of such problems.

Some of the points of conflict are shared by all interdisciplinary practices, particularly in emerging areas. Promotion and tenure in universities is particularly problematic both because of sociological resistance and the inability to use standard metrics (e.g., publication in established peer-reviewed journals) and the difficulty in evaluating new scholarly practices (e.g., how to evaluate the work of an art historian who works with

physicists when there are no physicists in the evaluation committees). We have noted the emergence of a cohort of "hybrid" professionals whose training includes a higher education degree in science or engineering and a separate one in arts, design or humanities. Most importantly, the dearth of postdoctoral funding within the arts and humanities immediately privileges certain pathways and creates other asymmetries.

Funding organizations have occasionally responded to these issues by setting specific interdisciplinary funding programs (for example, the INSPIRE awards at NSF and the new AHRC Hubs in the United Kingdom) but there remains an across-the-board problem of evaluation.

Other asymmetries exist when collaborators are situated in industry or municipal institutions. Such collaborators may not have what are called "terminal degrees" in the United States (e.g., a PhD or MFA), which can create conflicting situations in terms of funding attributions (for example, researchers in the gaming and entertainment industry often cannot be certified for teaching). We have mentioned elsewhere the stresses caused by differing Intellectual Property cultures that can contribute to these problems.

We have the impression from our limited sample of SEAD demographics that there are far more artists, designers and humanities scholars working in SEAD collaborations than there are disciplinary scientists. There are many artists-in-residence programs in science institutions, but almost no scientists-in-residence programs in arts, design, and humanities programs. We suspect that this is not an inherent in SEAD collaborations, but is a sociological asymmetry.

Though many of these issues face any interdisciplinary or transdisciplinary effort, SEAD practice faces particularly challenging obstacles because of a large variety, and depth, of asymmetries; this action cluster would be worthy of in-depth study and elaboration on best practices that could overcome the obstacles posed.

See Appendix 1 for a listing of specific Suggested Actions from the White Papers pertinent to this action cluster.

INCLUDING: Spurring innovation through diversity

4. Communities addressing global issues and local solutions

Inclusion in SEAD activity may mean consideration of under-represented groups as collaborators or audiences, on the bases of culture, gender, geography, age, and skills.

This is desirable for both societal and pragmatic reasons, ones motivated by current creativity and innovation theory. The internationalization of SEAD practice also foregrounds cross-cultural issues.

Many authors emphasize the need to support public projects that raise awareness of and the level of public discourse about science and technology. Accessible data visualizations are among the means that could promote understanding of the sensing and representational capabilities of various media technologies. Suggested supporters of such efforts include UNESCO, and groups in the United States such as the National Endowment for the Arts, the Foundation for the Alliance of Community Media, Centers and Institutes for Digital Literacy, the National Foundation for Educational Research, and the National Research Foundation. Authors encourage entrepreneurial approaches from such agencies, for example, by funding artistic works and then selling the results in order to recoup funds. A philosophy of "trade—not only aid" could help to encourage good-quality work and could create and sustain a market for science- and technology-based art.

Arts organizations, museums, and art magazines often focus on elite audiences, but extending beyond these groups could increase both transdisciplinary collaborations and the sharing of knowledge and expertise across broader demographic segments. A survey of works of art in various new media in museums, galleries, universities, and agencies could be instructive about different communities' values, tools, and methods. Equally revealing would be the websites and online portals that support dialogue about such varied works and the theories that inform them.

Many communities are acknowledging creative industries as an area of economic development. Design and manufacturing are increasingly emphasized in the United States and Taiwan. Some authors suggest that industry in Asia would benefit from transdisciplinary research involving science- and technology-based creative work. SEAD work could serve as a catalyst, reducing costs and increasing production in developing countries. Already, developing countries are benefiting from low-tech and DIY protocols and tools, though challenges persist. For example, some authors encountered technical problems exacerbated by extreme weather and environmental conditions that interfered with the operation of mobile phones. Cameras on mobile phones also prove unreliable for some SEAD fieldwork; the lack of resolution and inability to zoom results in lost details of insects and fungi being studied. Other pragmatic concerns present even greater difficulties, such as maintaining financial stability among farmers and scaling up successful technology-supported agricultural strategies.

Some authors envision an inclusive, transdisciplinary research agenda based on global-scale networks, including programs for graduate students to visit developing countries and conduct workshops or otherwise assist local researchers. Research in developing countries tends to be "authentic," embedded in the local communities and engaged with people's real and immediate needs more so than involving large-scale stakeholders and actors. Open-source hardware, open data, and open-access platforms and methods often prove useful. Authors suggest supporting science and art "ambassadors" who use low-tech solutions and citizen-science kits in order to share scientific protocols with various communities around the world. Farmers in particular could benefit from using mobile networks and learning to adapt them for their own needs.

Scientific entities organizing international conferences and symposia could include science-art exhibitions and talks on the benefits of science-art interactions. Organizers of art and science shows and fairs could promote inclusion by encouraging SEAD practitioners from developing countries to participate and by providing them with concessions and fee waivers. Promoting new works along with traditional art could have intercultural as well as educational benefits. Some authors believe this need is particularly strong in Asia. They suggest making deals with relevant cultural bodies to enable SEAD work; they note additional needs, including peer review processes, policy development, and the establishment of cohesive linkages among various community organizations. Global-scale collaborations could also benefit from a cross-cultural research program in which students in both the arts and the sciences could find interesting topics to develop. A globally shared and accessible "knowledge bank" could become a reference for topics and emergent SEAD curriculums. Wider adoption of the model of the practice-based doctorate could also support SEAD collaborations.

Authors suggest that funding bodies, research foundations, and creative institutions work with federal technology programs and organizations targeting SEAD-related work—as well as with individual stakeholders such as artists, scientists, and researchers—toward realizing creative projects and effectively promoting media literacy. We need to celebrate partnerships among creative individuals and industries that result in broadly useful new technologies. We also need to encourage entrepreneurship and work to overcome financial barriers limiting start-ups' access to new technologies.

Sensitivity to contexts and existing cultures requires special care when engaging in a cross-disciplinary collaboration. SEAD collaborators need to maintain openness,

flexibility, trust, respect for a wide range of practices in acknowledging authorship and credit, and receptivity to challenges to one's values.

Authors note that academic programs in media literacy and media arts attract more members of minority groups than other technology-oriented programs. Therefore, supporting media-oriented programs may help to counter persistent demographic imbalances among students and ultimately practitioners working with new technologies. Using media-technology strategies for public communication about science and technology topics could also foster greater readiness for scientific study.

Increasing interest in soft materials such as thread and yarn have potentials to improve STEM learning related to computer programming and mathematical topology. Authors suggest involving children in "sewable computing" knowledge and practices, to lay the groundwork for increased mastery of STEM skills and to increase women's participation in the electrical engineering and computer science professions. Workshops that use hyperbolic crochet, fiber arts, and other creative crafts could also reduce math anxiety and open effective and supportive pathways into math learning. Arts and crafts activities may level the playing field also for individuals from low socioeconomic backgrounds.

See Appendix 1 for a listing of specific Suggested Actions from the White Papers pertinent to this action cluster.

EMBEDDING: **Public engagement and negotiation**

5. Outreach, "citizen science," dissemination

Authors suggest reaching out to communities through a range of involvements that includes not only increasing awareness, but also actively involving community members in SEAD-related work. Authors note that print publications, websites, and videos can function as means for increasing awareness about the importance of interdisciplinary collaboration. Documentary films are especially cited as a medium for showing how precedents of prior collaborations among scientists and artists continue to be informative. Industry and government agencies are encouraged to note examples of early artistic experiments in digital media that have led to technological innovation. Such examples include games, simulations, human-computer interfaces, and multimedia search engines. These developments argue for better recognizing and supporting the role of artistic creation in economic and cultural advancement.

Relationships between industry and community organizations could support development of programs for people of all ages, in order to communicate results of scientific research and involve community members in creative activities reflecting scientific knowledge. Interactive seminars may be a way for artists, scientists, and the lay public to find application areas for knowledge generated by SEAD projects. Local TEDx (https://www.ted.com/tedx) venues, or other regular venues such as the Leonardo LASERS and those offered by other groups and organizations are another way of attracting audiences and encouraging collaborations. Meetup methodologies used in the hacker and maker communities are also effective.

Some authors describe a notion of "grassroots innovation" in which not only professional researchers, but community members engage in participatory design of potential solutions to local and global challenges. These authors call for local employers and members of city councils and other government agencies to acknowledge and support community-based creative spaces such as FabLabs, Maker Faires, wet labs, and hacker spaces. Job opportunities and calls, bids, and contracts for specific projects could be situated in these alternative R&D spaces. Projects especially well suited for such spaces might include disaster management, forms of civic engagement promoting ecological stewardship, "smart cities" efforts, and deliberation about ethical issues related to emergent technologies. Community collaborators could help to both develop new technologies and identify culturally appropriate applications. Urban farming is getting particular attention as an area orchestrating multidisciplinary expertise and promoting sustainable communities. Many authors note the importance of initiatives to encourage entrepreneurship, especially in rural communities.

Authors call for creation of maps, using new visualization approaches, to illustrate correlations of concepts in SEAD projects, geographic locations of collaborators, and so on. These authors also suggest sharing such maps broadly, through widely read science and art publications and general interest publications prepared for well-informed audiences. Many authors suggest creation of websites, including weblogs, to document SEAD projects of regional, national, and international scopes (which the XSEAD initiative is beginning to do).[4] Authors' refrains to provide more funding encouraging interdisciplinary work emphasize the varying scopes of SEAD projects and the associated needs for both involving community members and disseminating to communities of

[4] The XSEAD initiative is beginning to offer an online gallery and forum for documentation of SEAD works and discussion among practitioners. See http://xsead.org.

different scales. Authors express the hope that both national-scale funding entities and universities will heed these suggestions.

Authors stress that both curriculums and university structures need to evolve in order to encourage transdisciplinary work. Generally, tenure tracks persist within rather than across colleges, and this tends to be true even at the departmental level. Funding initiatives often exist in silos as well. Authors suggest creation of project grants, scholarships, and fellowships for students and faculty working in interdisciplinary fields. Science and engineering faculty, graduate students, and postdoctoral researchers often need specific encouragement to work with transdisciplinary arts interests. These curriculum development issues were discussed at length in *Beyond Productivity* (Mitchell, Inouye, and Blumenthal 2003), but once again the extension beyond IT poses real curriculum development challenges which are being addressed in a variety of venues that bridge existing educational structures and those within civil society more broadly.

One candidate area for cross-over activity could be workshops that "bring together choreographers and dancers, cognitive scientists, neuroscientists, and other academicians, scientists, and those in digital media and other technologies" (Batson, 2012) to frame one-year projects advancing knowledge from their combined perspectives. Soft materials such as yarn, and arts and crafts generally, present additional opportunities to promote transdisciplinary collaboration and STEM learning. A simple crochet pattern, for example, can yield models of hyperbolic planes that make mathematical concepts accessible. These are concepts that otherwise might seem elusive. Authors encourage public arts institutions and other community organizations to work with schools in creating a synergistic system through which people of all ages can engage, learn, and enjoy the mathematics underlying such creative activities. One author calls specifically for development of workshops to reduce math anxiety in teachers, parents, and students. In these workshops, "hyperbolic crochet, fiber arts, creative craft, and other engaging and non-threatening activities can open an effective and supportive pathway into math learning." (Kuhn, 2012) Authors note that arts and crafts designed to promote STEM education could be effective not only in schools, but also through community programs including both formal and informal mentoring, arts-related business initiatives, and outreach programs associated with museums, symphonies, and other public arts institutions. The increasing interest in arts and crafts could argue for cross-institutional sharing of materials, spaces, and other resources.

Authors suggest increasing outcomes-based interdisciplinary courses for both undergraduate and graduate students, to help students gain fluency in areas of intersection between disciplines. An initial challenge would be in breaking through preconceptions about the perspectives. Such courses could be offered as single electives or as part of an overall campus vision for transdisciplinary learning. Authors also point out advantages in developing a comprehensive study of cross-disciplinary course curriculums, as could be initiated through organizations such as the US-based College Art Association, Art & Science Collaborations, the Leonardo Education and Art Forum, the National Science Teachers Association, the Mediterranean-perimeter based YASMIN, and numerous other international organizations active in SEAD.

Authors further suggest that a new call for courses be initiated through SEAD (http://sead.viz.tamu.edu/). The resulting body of work could encourage collaboration and diminish the isolation so often experienced by SEAD-oriented researchers and educators. Inventorying the results in a dedicated website could ease comparison of transdisciplinary efforts, which may help to heighten quality as educators share information about their curriculums through the platform. Helpful functions would include a cloud-based resource of syllabi, a blog, links to best practices in interdisciplinary curriculums, and announcements of international conferences in art-science-humanities. One author suggests expanding the SEAD CDASH website (http://www.cdash.org) to include such functions; XSEAD, HASTAC and other emerging platforms could be other possibilities. Authors suggest tie-ins to existing academic journals and websites. Ideally the emerging platform would facilitate pooling of expertise and resources for innovation among educational institutions internationally. Of course, such web resources could extend to become teaching tools, used along with other media such as documentary films.

The means through which SEAD work is disseminated—printed and Web-based publications, films, videos, and social media—can also be the means of recruiting collaborators and forming partnerships. Transmedia can also be helpful in codeveloping projects and workshops. Authors suggest tapping yet-unrealized uses of the interactive capacity of mobile media. The example of e-agriculture, in particular, suggests opportunities for employing a multidirectional model of communication, in which every node of the network can be both a consumer and producer of information. Beyond receiving expert information through a hierarchical mode of one-way transmission, farmers could send responses and perhaps data from the field, to form a more egalitarian and information-rich exchange. In the realm of dance, partnerships with members of

businesses and larger communities could meaningfully broaden experimental studies. Sample topics might include: Problem-Solving in Business through Dance; Improving Learning through Attention Development (perhaps especially for high school students); Dance and Health; Memory and Movement in Aging; and Dancing with Challenges (as in developing new therapeutic treatments for Parkinson Disease).

See Appendix 1 for a listing of specific Suggested Actions from the White Papers pertinent to this action cluster.

SITUATING: An emerging ecology of creative places

6. "Alt spaces"

In parallel with the increase in distributed resources such as open-source software and MOOCs (Massive Open Online Courses), more and more SEAD-compatible places for meeting and making are appearing in local communities. DIY (Do It Yourself) and DIWO (Do It With Others) organizations, known as Fab Labs, hacker spaces, skunk works, and maker places, provide shared access to knowledge and technologies. Such places can answer authors' calls to support decentralized, flat, peer-to-peer, and community-focused organizational models. These places can also serve as incubation centers and showcases for technology and manufacturing companies. Such "alt spaces" promote a culture of tinkering and STEM inquiry through self-directed, creative interaction with materials. "Thinking with things" can bring people together and provide powerful ground for learning scientific and artistic principles. Authors call for careful research and evaluation of these learning effects. Some suggest that universities could promote transdisciplinary collaboration and residencies in community-based alt spaces as general requirements for career advancement. Permanent spaces such as fabrication shops and resource-rich lab-studios are also needed on campuses to support SEAD work and learning. Libraries and university centers on- and off-campus could provide spaces for mixed-age school groups to access materials and engage design projects. Benefits of the networks of places and people created through alt spaces have been demonstrated in many communities, but in some areas there are regulations inhibiting wet-lab experimentation outside of university settings, which may be slowing innovation. Broader involvements of community members can be achieved through art and design competitions, crowd-sourcing idea generation, and "citizen science" initiatives. Stakeholders might include community members, city councils, faculty and practitioner researchers, galleries and artist collectives, museums, public libraries, funding agencies, and chambers of commerce. Networking across geographic sites, perhaps internationally, could form a set of think tanks for co-creative transdisciplinary work.

A large number of Suggested Actions target specific strategies. These new social developments are becoming crucial components of the SEAD landscape, but there has been little study or investment into how to build sustainable networks of intervention.

See Appendix 1 for a listing of specific Suggested Actions from the White Papers pertinent to this action cluster.

SENSE-MAKING: Multimodal knowledge and ways of knowing

7. Integrating understandings through the SEAD perspectives

The value in building a comprehensive understanding of human cognition and perception, in all its complexities, is a thread mentioned throughout the White Papers. Sense- and meaning-making are central agendas, with many authors striving to avoid reductionist approaches that fail to capture the integrative natures of human experience and creativity. Even if not advocating for a specific modality or research area, authors are apt to mention the need to secure funding for cognitive research and the need for research that connects the understanding of learning processes and K-12 SEAD education with both higher education and the community at-large. Authors also used the term "embodied cognition" frequently to express the need for seeing connections between the body, the brain, and the sweep of human experience.

Many authors wrote about sense-making from personal experience, explaining how their transdisciplinary foundation aided them as adult professionals. Specific topics include projects developed to stimulate learning, particularly in K-12 environments; perception studies; embodied cognition; how movement (e.g., dance) aids cognitive research; and the use of code to engineer sound (audio) projects and blend SEAD perspectives. Authors also document the growing body of research on specific "design thinking" that is fundamental to the intersection of the sciences, engineering, arts, and design. Several authors point to studies that show arts training is associated with higher academic performance, such as those published by the Dana Foundation (Gazzaniga, Ashbury, and Rich 2008; Posner et al. 2008). Many authors advocate for such "evidence-based" approaches.

Our external reports expanded on the suggestions, with some offering specific examples that demonstrate the value of collaborative work in sense- and meaning-making. The "Painter's Eye" project, funded by the Wellcome Trust Sci-Art program, was one such example. Undertaken under the leadership of filmmaker and scientist Dr. John Tchalenko and neuroscientist Chris Miall, this 1998 Sci-Art funded project involved the

collaborative efforts of the portrait painter Humphrey Ocean as well as a team of scientists from Oxford and the United States. The initial exploration opened up new ways of thinking about how portrait painters work. London's National Portrait Gallery exhibited the scientific work and the collaborators later received additional funding that allowed them to make more discoveries about the physical and mental processes involved in portraiture (Wellcome Trust 2002).

Key concerns in the sense- and meaning-making area intersect with those raised in other SEAD action clusters: How do we understand collaborative working methods scientifically? The NSF-sponsored "Art as a Way of Knowing" conference, organized by the Exploratorium, focused on how different ways of knowing can interact productively. Robert Root Bernstein's White Paper analysis of successful scientists and engineers highlights the role of arts avocations in their work. A prevalent interest in how the various human senses "play" together is reflected in reflections on sonification, haptics research, and embodied knowledge. Does the specialization scientists bring to creative research projects obscure artistic contributions and knowledge, and vice versa? How do we develop strategies that aid in building cross-disciplinary vocabularies, tools for SEAD collaborators who are inexperienced in specific types of relevant research, and other support mechanisms for working together in research and evaluation? Authors also mention less direct but equally important considerations; the need to comprehend protocols for human-subjects research, for example, brings larger social goals into play when developing a scope of research. Additional "sense-making" activity areas noted include neurosciences, cognitive sciences, life and health sciences, as well as human-computer interaction and human-centered computing.

See Appendix 1 for a listing of specific Suggested Actions from the White Papers pertinent to this action cluster.

DOCUMENTING: Recording and transmitting

8. Capturing, publishing, curating, archiving

The SEAD community of practice finds itself innovating in both the form and content of their research and creative practice. In general they have been "early adopters" and often developers of new forms of multimedia arts and performance. They are also innovators of research methodologies and modes of collaborative scholarship. Though these claims are not specific to the SEAD area, they involve specific obstacles and opportunities that a number of the SEAD authors identify. Many of the transformations underway—such as open-access publishing, multimedia and online publishing, social media, and new forms

of scholarship—are accentuated because the SEAD community of practice bridges very different disciplinary cultures. Complications arise from differing practices with regard to intellectual property and authorship, modes of documenting work, and sharing work with peers and broader audiences. Several of the White Papers emphasize concerns about conservation and archiving of unstable media and preservation of the work of pioneers in the field. Again, this concern is not specific to the SEAD area, but it becomes particularly acute in the transdisciplinary context, and thus deserves attention. The priority given to this area is signaled by the sibling XSEAD project, which is developing an online interdisciplinary platform for documenting and showing work, both scholarly and creative; a number of other platforms are also under development internationally.

It is clear that the SEAD community will be engaged in many experimental and innovative approaches, which could be transferable to other areas of research. Several authors address forms for publishing, documenting, archiving, and curating of both original works and the scholarship surrounding them. It is important to note these "infrastructure" issues, which are driven in large part by digital capabilities and which bridge those of other interdisciplinary research areas.

Scholarly and professional societies and organizations that have played key roles in these areas during the past fifty years themselves are undergoing rapid evolution and restructuring. Resolving these new methods will require the kind of rethinking espoused by Cathy Davidson and David Goldberg in their 2009 report "The Future of Learning Institutions in a Digital Age" (2009).

See Appendix 1 for a listing of specific Suggested Actions from the White Papers pertinent to this action cluster.

LEARNING: Tapping into the passion and creativity of lifelong curiosity

9. Sharing blended experiences

Blended learning experiences transect all forms of formal and informal education. In the past ten years there has been an increase in the number of higher education programs that house faculty from multiple disciplines (Evans 2012). Some middle schools include traditionally structured arts programs to bolster science, technology, engineering, and mathematics (STEM) learning. SEAD discovered 35 charter schools in the United States with the title of "STEAM Academy." Among them, the "A" is defined unevenly, attributed to "applied mathematics," "aeronautics," "humanities and language arts," and "arts." Common Core curriculum standards intended to address the needs of a global

economy are embraced by 45 states (Council of Chief State School Officers 2013). In the United States, from the Bush Administration's "No Child Left Behind" act to the Obama Administration's "Race to the Top" initiative, learning continues to be largely defined as the acquisition of separately delivered skill and knowledge areas.

To assess the value of transdisciplinary learning, there is a need for research that can identify, examine and evaluate relevant theoretical frameworks. Theories of embodiment, which address forms of knowledge and learning related to hands-on and project-based experiences, have been developed within the fields of philosophy (Husserl 1983), architecture (Downing et al. 2008), art (Penny 1997), mathematics (Nemirovsky 2009), and others. Related studies in cognitive learning, theories of emergence and affordance, and literature about technology-based knowledge transfer hold potential to contribute to such understanding (Williams 2012).

Other data that can contribute to understanding of SEAD learning includes statistical factors on graduation rates, higher education enrollment, career entries, and results from standardized testing. Human factors such as attitude and self-identification of professional expertise can provide a basis for understanding relationships between blended learning experiences, excitement, and engagement. Impacts resulting from "innovation thinking" can provide knowledge about creativity that catalyzes work force development. Valuable input from studies of engagement by under-served populations may be applicable to other population segments, for example, literature on the role of family and community in the learning process (Lewis et al. 2010).

SEAD learning enables invention and innovation by blending the arts and sciences. As a partial legacy of formal education, "hacker spaces" and "maker spaces" proliferate but are not usually engaged in established research frameworks that can provide understanding about the excitement they have engendered and the potential they offer. Such community spaces provide a rich ground for research on "thinking with things" (Kuhn 2012).

Many tools to support SEAD learning have been developed. Open source frameworks such as Processing, kits such as Instructables, and creativity support tools proposed by NSF-funded projects have built a rich repository to research best practices (CreativeIT 1999). While such tools have been studied as closed systems, more work is needed to assess the impact of learning with multiple tools, as well as to broadly assess how they contribute to computer literacy (Presley 2012).

If these areas for research are further articulated, new ground can be gained to establish SEAD learning as a powerful way to address twenty-first century networked learning. Imagine K-12 administrators embracing research programs and public service components that take on grand challenges; broad-scale partnering across different domains that link formal and informal, private and public groups and resources; and models that help to structure inquiry-based learning for all ages.

Should SEAD learning become a field of its own, or a "field of fields?" Connected networks have opened niches for aggregation and matchmaking. While some advocate for closing "silos," others believe linking and nurturing deep disciplines will mine rich resources enabled by them while reinvesting them with greater relevance to non-practitioners.

An ecological model is a valuable metaphor for envisioning learning experiences based on a "systems approach." Pedagogical improvements include a move to decentralized, distributed, and integrated forms of learning that mesh with the organic structure of information flow. Courses that examine and compare methodologies and tools employed by artists and scientists can foster understanding of process and outcomes across disciplines. Student-centered models redefine faculty as facilitators or co-creators of knowledge. There is a need to support real time, virtual connections between classrooms and private, corporate, and research groups that can help them become self-organizing and less hierarchical (Cenkl 2012).

We envision twenty-first century learning as a dynamic system by those of all ages who employ multimodal and perceptual approaches alongside analytical, statistical, and computational ones. Such learners will creatively formulate *the right critical questions to ask* of new technology, and—appropriately—will then assign to computational systems the most critical problems to solve.

Coalitions among private foundations, corporate entities, and learning institutions have recently blossomed. Challenge projects and service-based learning models have activated partnerships between middle and higher educational institutions. Urban areas and those near research and business centers are in a better position to leverage support to benefit local and regional economies. Rural areas without access to institutions of higher education need collaborative networks for resource sharing. Home schooling groups and community maker spaces would benefit from increased access to networked facilities and

resources. Initiatives to improve local economies can be bolstered with structures that support global outreach and collaboration (Quintana 2012; Brown 2012).

While partnerships among higher education, business, and K-12 schools are more frequent today, they are often led by visionary individuals; when these individuals change focus or lose funding, the partnership often ceases. The contextual nature of such collaborations cannot be reproduced in an overarching way, but it is entirely possible to create a structure of support for matchmaking to broker, and resources to stimulate customized partnerships on larger scales. Building partnerships can involve developing curriculum that spans multiple levels and provides a smoother transition to higher education or career entry. Networks can focus on initiatives to resolve issues such as accessibility, resources, formal-informal partnerships, professional development, materials and resource collections, and opportunities for training. Exemplars of SEAD learning could partner to develop a practitioner- and designer-generated taxonomy of courses to build best practices (Williams 2012).

SEAD's vision for lifelong learning brings together three important concepts for an ecological transition to twenty-first century learning:

Innovation. All SEAD practitioners are creative. The impact of collaborative engagement across SEAD areas is transformative, and is already underway in many arenas.

Creativity. Encouraging creativity is key to realizing the next generation of artists and scientists. The "creativity crisis," showing that while IQ scores have risen, creativity scores have consistently decreased, needs to be addressed (Kim 2011).[5]

Broadening participation. Given current educational methods, most studies show young people don't see STEM fields as interesting. Integration of sciences and engineering with arts and design can improve motivational aspects of learning.[6]

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[5] In "The creativity crisis: The decrease in creative thinking scores on the Torrance Tests of Creative Thinking," Kim examines The Torrance Tests of Creative Thinking (TTCT), which was developed in 1966 and renormed five times: in 1974, 1984, 1990, 1998, and 2008. The total sample for all six normative samples included 272,599 kindergarten through 12th grade students and adults. Analysis of the normative data showed that creative thinking scores remained static or decreased, starting at sixth grade. Results also indicated that since 1990, even as IQ scores have risen, creative thinking scores have significantly decreased. The decrease for kindergartners through third graders was the most significant.

[6] Personal communication, email, from Brian K. Smith to Carol LaFayette, December 3, 2012.

See Appendix 1 for a listing of specific Suggested Actions from the White Papers pertinent to this action cluster.

COLLABORATING: Methodologies working across disciplines and institutions

There are good reasons for establishing disciplinary practices, and certain problems require "drilling deep" into narrow areas of knowledge. Similarly, delimited human organizations are necessary to articulate functionalities and operational feasibilities. But many real-world problems require integrative cross-disciplinary approaches that require partnering between different kinds of organizations. There is a large body of research on practice and best methods in academic, commercial, and municipal contexts to accompany practices that require collaboration and partnering. We have been struck by the large amount of literature on interdisciplinary, integrative, and holistic studies and the emphasis that many prior reports place on recommendations that address the collaboration problems faced by individuals and organizations. Recent work, for instance by Allen Repko and William Newell, has led to substantial consolidation of interdisciplinary theory and practice (Repko 2007; Repko 2012; Repko, Newell, and Szostak 2012).

The work of SEAD practitioners draws on this prior body of collaboration practice, but the broad range of disciplines involved poses particularly hard problems. There are different scholarly practices in many of the arts and humanities that privilege the individual artist or scholar. Intellectual property regimes vary and are changing across SEAD research. Methods for showing work to communities of peers and the larger public are heterogeneous. Institutional cultures vary extremely, from individuals in large companies or universities to artists in collectives; systems for validating individual merit and public recognition are dissimilar. In reviewing the White Papers and the Suggested Actions, we note consistencies in the obstacles and difficulties reported, yet there is a lack of any systematic collaboration methodologies or explicit acculturation to reconcile diversities. Networked culture creates additional situations and needs including the rapidity of interactions, mid-level partnering across organizations, and the mixing of online and physical collaborating. There have been significant investments in science and engineering for developing collaboration platforms and systems that often are not present in the arts and humanities, creating additional asymmetries that challenge collaborative practice. Some examples of SEAD consortia exist in Europe due to funding mechanisms that favor multinational, multidiscipline formal collaboration networks. Yet very few

SEAD practitioners have any formal training in collaboration techniques and best practices, except within project management training. It is clear that the improvement of collaboration methodologies that span the range of disciplines often faced by SEAD practices is a key area for study and development.

Beyond Productivity (Mitchell, Inouye, and Blumenthal 2003) already highlighted the issues surround the need to address collaboration methodologies. In particular they referred to the work of Mihaly Csikszentmihaly, who articulated a systems view (1988, 326) and spoke of the need to articulate a social system made up of individuals, knowledge domains and institutional structures.

10. Collaborations between individuals and disciplines

SEAD practice requires individuals from differing disciplinary and organizational backgrounds to think, create, and work together. Many of these collaborations span national boundaries and many of the most successful collaborators are geographically mobile. The international character of collaborations is common in scientific and engineering projects, but less so in the arts and humanities. These groups also have differing value systems in articulating emphases on the global and the local. In reviewing the demographics (see Appendix 6) of our White Papers participants we were struck by other facts that have impacts on SEAD collaboration practice: (1) Our participants are almost exactly gender balanced, even though we followed no particular recruiting approach. This gender equity appears to be characteristic of the SEAD community of practice. (2) Our participants are in majority from arts, design and humanities (64%). Increasing the participation of scientists, engineers, and mathematicians is an issue for further growth of the field. (3) As noted above, we identified a cohort (20% of participants) whom we have called “hybrids”: that is, they have an advanced degree in one field of science, engineering, or mathematics, and a separate degree in a field of arts, design, or humanities. We have the impression more and more individuals are combining perspectives and effort is this way. Such individuals may play important translational roles in collaboration practice. Some White Papers authors point out that individuals used to working on their own who enter collaborative relationships need to maintain open-mindedness allowing for ongoing adjustments of preconceptions about partners’ disciplines. Likewise, educating fellow collaborators must be ongoing.

11. Partnering across organizational boundaries

A wide variety of institutional structures underlies SEAD disciplines; this underpinning varies internationally. In some countries, polytechnics are separate structures from

schools of art and music. Entrepreneurial cultures also vary widely, as do connections between higher education and industry. As noted, much innovation has been occurring in "alt spaces" that form outside of conventional organizations. The traditional innovation "triple helix" of universities, government, and industry bypasses the loci of much SEAD creative work. As described in the "Situating" cluster above, SEAD practitioners are heavily dependent on mobility between formal and less formal institutional contexts; evolutions such as the Fab Lab movement have been one response to these emergent practices. The heterogeneity of organizations that need to partner for successful SEAD collaborations poses legal, economic, and operational difficulties; future solutions to these challenges may need to depart from traditional funding agency models. Business practices include widely accepted approaches, such as Strategic Alliance methods, for raising the success level of partnerships. The introduction of programs for SEAD collaborators to learn such management methods could also benefit SEAD partnerships.

See Appendix 1 for a listing of specific Suggested Actions from the White Papers pertinent to this action cluster.

THRIVING: SEAD ingredients as essential contributors to healthy communities

Many of our contributors raised concerns about the SEAD discourse both in terms of possible instrumentalization of the arts, design and humanities but also because culture and values are often backgrounded in the kinds of issues and Suggested Actions that are proposed. Creativity and innovation are not goals in themselves, but means to enable thriving and healthy individuals, communities, businesses, organizations and a sustainable planetary civilization. Science and technology, as means of knowing and being in the world, carry implicit and explicit values that can come into conflict with other human aspirations and must be articulated and negotiated with other systems of beliefs and social practice in our societies. Often such concerns are addressed through education outreach, public communication, and other secondary or parallel mechanisms to research and development (there are exceptions, such as the integrated approach in nanotechnology and society). The rapid growth of the creative industries and knowledge economies has in some cases been at the expense of investment and development of the arts and humanities that must be equal partners in SEAD strategies. One promise of the SEAD ambitions is to foreground such issues as part of the deeper collaboration strategies between practitioners in the different disciplines.

In recent years economists have developed ways of taking into account well being and happiness as part of the way of understanding and comparing societal development at the level of individuals and groups. Health professionals insist that well being requires a combination of factors, from biological to psychological, at both the individual and group level. A number of Suggested Actions engage with how ethics, values, health and happiness, as well as joy and well being, can be articulated as part of SEAD approaches.

12. Ethics and values

Historians and philosophers of science and technology have developed a good understanding of the way that ethical issues arise in the scientific method itself, the social practice of science and engineering, and the content of science and engineering. Historians, political scientists and social scientists have a growing understanding of how organizations and societies deploy deeper values and negotiate changing ethical landscapes. SEAD methodologies should seek to foreground issues of ethics and values and not defer them to secondary discussions outside of the SEAD community. As a community of practice that straddles several disciplinary value systems it is uniquely placed to take leadership in these discussions.

13. Well being and joyfulness

The passions and dreams that drive the creative arts in all their varieties are essential contributors to thriving communities, from the deep cultural engagements of celebration and commemoration to personal joy and happiness. The arts, design, and humanities are important approaches that in themselves contribute to healthy, sustainable societies; their contributions to the interplay of "ways of knowing" require an acknowledgement that investment must be made in both the SE and AD segments of SEAD practice.

See Appendix 1 for a listing of specific Suggested Actions from the White Papers pertinent to this action cluster.

SEAD WHITE PAPERS METHODOLOGY

The process used to research and craft the SEAD (Science, Engineering, Art, Design) White Paper Report was drawn from the collaborative nature of the SEAD network, which is a community of advocates united by a vision of the importance and value of research and creative work across the arts and sciences. Initially, two groups received NSF EAGER grant funding: NSEAD and XSEAD. NSEAD (now SEAD) proposed the White Papers project as a way to build community around perceived challenges and opportunities relative to engaging art and design with engineering and science disciplines. The White Papers Working Group was designated as the mechanism to conduct this research for the network, to structure actions, and make them relevant to stakeholders.

Working with an internationally renowned advisory board, SEAD Principal Investigator Carol LaFayette and the White Papers Working Group Cochairs Roger Malina and Carol Strohecker wrote and released a call for papers to incorporate the ideas of active professionals, ensure that the proposed outcomes would benefit the diverse SEAD population, and draw both primary experiences and secondary research into the analysis. In addition, they asked authors to provide "Suggested Actions" that indicated how their ideas could better involve stakeholders and inform other SEAD initiatives.

In response to this call, authors submitted 73 abstracts, 55 full White Papers, and 260 Suggested Actions. The breadth and diversity of the authors and the topics they examine offer a window into the current landscape of collaborative art, science, technology, and design.

Who are the authors?

White Papers were written by one lead person (coordinator) or included a group of interested people (a working group) coordinated by a lead person. While some participants/authors developed their abstract as the work proceeded, all the participants needed to endorse the final paper. Not all submitted abstracts resulted in a White Paper, although the abstracts also included Suggested Actions. Professionals from the SEAD community were a part of the research and review process to insure that the proposed outcomes would benefit the SEAD cohort. We intentionally viewed the White Papers as living documents posted in an open-access website; we posted improved versions of the papers as we received them.

What was the process?

Not all submitted abstracts resulted in a White Paper, although the abstracts also included Suggested Actions. Professionals from the SEAD community were a part of the research and review process to insure that the proposed outcomes would benefit the SEAD cohort overall. We intentionally viewed the White Papers as living documents posted in an open-access website and posted improved versions of the papers as we received them.

What is the scope?

We requested that authors include roadblocks and opportunities for enabling broadly interdisciplinary work. Our goal was not to examine interdisciplinary work in general, but rather what is happening in the SEAD context. In presenting this perspective, we made it clear that SEAD assumed a broad view of the Arts to include not just materials-based creativity, but also liberal arts such as the Humanities.

International perspective

Our call for papers specifically stated that we were interested in including an international perspective in the planned meta-analysis of the White Papers, although the scope of specific papers need not include international collaboration issues. This resulted in many papers from authors around the world. The demographics provided in Appendix 6 indicate the level of success in getting an international snapshot of the state of SEAD studies. We recognize, however, that our results are dominated by the English-speaking world in a way that does not reflect the community of practice itself. In addition, the low representation from outside North America and Western Europe does not reflect the vitality of work currently going on in Eastern Europe, Asia, Central and South America, and Africa. We were able to achieve a respectable breadth of international inclusion within the timing of the initiative, but even greater cultural diversity could become possible in a follow-on effort with expanded resources and parameters.

Purpose of the White Papers and the role of stakeholders

The call for papers requested proposed actions and specific stakeholder information. We emphasized that Suggested Actions were intended not for the National Science Foundation, the funder of the project. Rather, the authors' focus was to be on the broader

landscape of stakeholders and beneficiaries of their SEAD initiatives. These groups might include a variety of agencies, foundations, educational institutions, nonprofits, or other "agents." Similarly, although the White Papers initiative was not an effort to claim that art advances science or vice versa, individual authors did express such points of view. The SEAD network has given voice to these practitioners individually and collectively.

We defined stakeholders as consumers of specific products or technologies, government agencies, SEAD students and professionals, and all who have a vested interest in SEAD success. Thus the intention was to extend the analysis beyond academia and include, for example, businesses and municipal economic development councils.

Authors did not need to address *all* stakeholders. The idea was that each paper's proposed actions would clearly address specific stakeholders, identify barriers and opportunities, and recommend strategies. This flexibility allowed for responses that were relevant outside of academic contexts, as well as those having implications for curriculum development.

Typology Comparison

One of the challenges was developing a typology to encompass the diversity of ideas and perspectives. The SEAD grant had identified 4 primary areas for investigation:

1. Advocacy for research and creative work
2. Advocacy for learning and education
3. Advocacy for partnership
4. Advocacy for culture and economic development

Earlier Reports used a number of frameworks. For example, the *Beyond Productivity* (Mitchell, Inouye, and Blumenthal 2003) report, which was seen as a precursor to the SEAD effort, had presented approximately 30 suggested prioritized actions, and 12 of these were well articulated.[7] This report divided stakeholders into four fluid categories.

[7] *Beyond Productivity* was issued by the National Academies Press in 2003 and is available for download at http://www.nap.edu/catalog.php?record_id=10671). The report was edited by William J. Mitchell, Alan S. Inouye, and Marjory S. Blumenthal.

1. Industry
2. Funders
3. Community
4. Academia

Like the authors of *Beyond Productivity* (Mitchell, Inouye, and Blumenthal 2003), we found that practitioners span categories. Some practitioners place themselves within the community, but many practitioners situate their creative practices within academic or industry contexts. Placement is an issue for research as well, which might occur in an industrial or academic context.

As we began to synthesize our conclusions, it seemed that rather than reiterating specific suggestions already issued by many previous reports, we would structure this document around action clusters receiving a critical mass within the White Papers' comments and suggestions. These clusters may frame questions that specific stakeholders can use in considering possible interventions. Many of the action clusters pertain to the interests of multiple stakeholders, requiring the interplay of public and private actors and organizations.

Within each of the clusters identified, we identified Suggested Actions that encompassed and enlarged our four framing objectives of culture and economic development, research and creative work, learning and education, and partnership and collaboration. The 13 are listed in the Synthesis section of the report (see p. 5).

Meta-analyses

As part of our White Papers methodology, we issued an open call to all the SEAD White Papers authors to contribute to the final report via a "meta-analysis" of the White Papers. The goal was to develop a meta-analysis methodology yielding an overall portrait, or synthesis, of the state of mind of the SEAD community internationally.

Although generating sufficient statistics was not a goal of the SEAD White Papers initiative, a Suggested Action for a "Beyond Productivity II" report would be to do so. The meta-analysis employed here uses research synthesis and systematic review as well as purely statistical evaluations, but by viewing the 55 White Papers as a single text it is possible to use meta-analysis approaches (e.g., keyword frequency).

Four meta-analyses were added to the project when interested parties noted gaps in the White Papers collection. This collection also met one criterion of the project: The SEAD community of practice should be self-critical and self-analytic using the tools and data now available on our own behaviors and practice.

These meta-analyses are posted at http://wp.me/P2oVig-qa. The authors and titles follow:

1. Harp, Gabriel. SEAD Themes and Insights Meta-Analysis: From Conflict to Coherence
2. Lapointe, François-Joseph. A SEAD Network Analysis of White Papers
3. Miranda de Almeida, Cristina. Meta-Analysis of SEAD White Papers with a Focus on Research and Creation
4. Zilberg, Jonathan. A SEAD White Papers Working Group Meta-Analysis

We have included the insights provided by these papers in the 13 Suggested Action clusters in this report. Some points raised by these authors are worth emphasizing.

1. The C. P. Snow "two cultures" thesis is again revealed as a flawed conceptual framework

Both Lapointe and Zilberg, using different approaches, conclude that today's SEAD community of practice demonstrates that the "two cultures" framing of the situation is neither accurate nor useful. In a detailed network analysis of 40 of the White Papers, Lapointe demonstrates that the data does not support a "two cultures" description of the actual research and practice networks; in addition, he highlights the existence of a large cohort of "artscientists" whose practice bridges the cultures and, accordingly, who cluster in the network analysis. The paper reveals the power of network analysis for the study of intertextual comparisons and exemplifies methods for research using social and textual analytics. Zillberg points out that many of the SEAD White Papers authors problematically assume a "two cultures" premise and reflect it in their discourse. He argues that that this insufficiently questioned premise significantly compromises the SEAD network's potential. The title of our report, "Steps to an Ecology of Networked Knowledge and Innovation" is a constructive attempt to shift the paradigm of SEAD discussions beyond a "two cultures" premise.

2. SEAD practitioners should be cautious about describing the impact of their work on science.

In analyzing more than 20 of the White Papers, Zilberg issues a note of caution about the value of SEAD research in enabling new scientific discoveries. He notes that cross-disciplinary work can and does contribute to scientific creativity and science education. But in terms of the most basic and direct criteria, he argues, SEAD cannot yet be seen as a fully transdisciplinary project because it has not been demonstrated that the arts can contribute in a systematic manner to basic science. Nevertheless, it is possible that SEAD-style projects have inspired scientific work. It seems, he concludes, that not only is clarity required about the nature of the disciplinary relations, but perhaps some basic research should be conducted to look into their particular contributions and effects more closely. Nevertheless, it is worth noting that several scientists participating in the study by Strohecker et al. describe ways in which arts and their work with artistic collaborators have influenced their scientific thinking, discoveries, and inventions.

3. Converting Suggested Actions into Process Strategies.

Harp and Miranda de Almeida provide in-depth alternative analyses of the 260 Suggested Actions in the SEAD White Papers. Harp derives 41 action areas, grouping insights into the domains of people, platforms, and practices. He notes that Tardif and Sternberg (1988) present similar themes, identifying processes, persons, products, and places as important clusters of focus for creativity research. Miranda de Almeida analyzes from the perspective of Theory of Action; her methodology offers a tri-dimensional matrix to deal with six different kinds of action, four kinds of stakeholders, and four spheres of integration/collaboration.

The meta-analyses also contribute constructively to the rationale that motivates the overarching Suggested Action that the time is ripe to initiative a “Beyond Productivity II” study and report, aiming to accelerate SEAD agendas.

Synthesis process

The synthesis process was carried out by the authors of this report at a weekend retreat hosted by The Institute of Applied Creativity at Texas A&M University.

As stated some 260 separate Suggested Actions were identified. Rather than synthesize or prioritize these Suggested Actions it was decided to 'cluster' them into groups of related Suggested Actions. Secondly rather than group them by stakeholders to whom they are addressed, as was often done in previous studies, it was decided to work within the network metaphor and cluster the actions around key "processes." These are key processes needed to overcome obstacles to SEAD practice and take advantage of new opportunities. Stakeholders can use these processes to develop roadmaps and planning. One of the major findings in this report is this "process" orientation within the networked knowledge metaphor we have adopted.

A final contribution to the synthesis process was the four "meta-analyses" which each analyzed sub-groups of White Papers. The process used for synthesizing was therefore carried out transparently through open access interim conclusions and sought to provide a broad scheme rather than narrow prioritization; such prioritization could be the object of subsequent studies.

Finally the draft report was circulated and presented at the May 16, 2013 SEAD symposium in Washington DC. The feedback resulted in fine-tuning of this report.

Summary

The final White Papers (posted at http://seadnetwork.wordpress.com/white-paper-abstracts/final-white-papers/) represent a spectrum of interests in advocating for transdisciplinarity among arts, sciences, and technologies. All authors submitted plans of action and identified stakeholders they perceived as instrumental in carrying out such plans. The individual efforts led to an international scope. One of the important characteristics of this collection is that the papers do not represent a collective aim toward an explicit initiative. Rather, they offer a broad array of views on barriers faced and prospective solutions. In summary, the collected White Papers and associated Meta-analyses began as an effort to take the pulse of the SEAD community as broadly as possible. The ideas they generated provide a fruitful basis for gauging trends and challenges in facilitating the growth of the network and implementing future SEAD initiatives.

CONCLUDING REMARKS

This effort began with a call to the international community for White Papers addressing opportunities and obstacles in the SEAD community of practice. From the 73 abstracts and 55 White Papers submitted, we received 260 Suggested Actions. Many of these reflect a broad consensus in several areas; we have found that many areas of concern also appear in the inventory of more than 40 prior reports (see Appendix 5). Other Suggested Actions are novel or reflect emerging areas of practice. We hope that stakeholders seeking to accelerate SEAD agendas will find this large community-based study useful.

The draft synthesis of this report was delivered at the conclusion of the SEAD grant and posted online in open access, inviting feedback and comment.[8] Eearly feedback played a role in the shaping of the final report; going forward, comments have enabled connections among SEAD practitioners and the type of transdisciplinary explorations that we hoped the report would spark.

Our overall impression is of a dynamic, vibrant, and rapidly growing area of practice. The SEAD community is the inheritor of many decades of development of practices and agendas. Many opportunities exist for contributing to urgent questions that are priorities in our communities. The nature of transdisciplinary collaboration is such that there are many stakeholders who have interests in the success of the SEAD agenda and may be in positions to remove or reduce obstacles. The interface to funding agencies and non-profit organizations poses particular problems in articulation that need attention.

As indicated in the opening of this report, there has been a sense that it would be useful to stimulate a new national study that would follow on from the *Beyond Productivity* (Mitchell, Inouye, and Blumenthal 2003) report. This still seems a desirable goal, one that this White Papers study serves by beginning to map the new landscape.

We would like to thank members of the large international community who have contributed to the SEAD White Papers process and hope that the results will be useful to each individual and organization in their own context.

[8] Feedback on the draft report was collected at http://wp.me/P2oVig-qF. The final report is at http://wp.me/P2oVig-3b.

SUMMATIVE CALL TO ACTION

Converting Ideas and Practices to Concerted Action: *Beyond Productivity II*?

In developing the SEAD White Papers study, we have compiled a bibliography of more than 40 prior reports that address the needs and problems faced by the emerging SEAD community (see Appendix 5). This compendium, going back 50 years, was both encouraging and discouraging; it is clear that many of the opportunities and obstacles now facing the SEAD community were identified and worked on in the past.

But it is also clear that there has been an almost explosive growth of the community over the past 10 years, with increasing interest in industrial innovation and economic growth agendas, the establishment of university programs of a wide variety, and the emerging vitality of the maker and hacker communities and other civil society actors.

Of particular importance to this work was the *Beyond Productivity* report produced by the US National Academy of Science in 2003, which was edited by William J. Mitchell, Alan S. Inouye, and Marjory S. Blumenthal on behalf of the Committee on Information Technology and Creativity with support from the US National Research Council. Some of the recommendations of this report have been implemented; many have not.

Several things have changed since 2003, which might motivate a new national study in the United States as well as in other countries.

Whereas the focus of *Beyond Productivity* was information technology and creativity, the span of disciplines invested in by SEAD practitioners now ranges well beyond these, from the biological and health sciences to space exploration to nanosciences. New opportunities and obstacles have arisen that were not addressed by the *Beyond Productivity* report. The NSF and NEA workshops over the past three years have brought together very disparate research communities that do not often convene in the same venues.

Collaborative practices are evolving rapidly, promoted in part by online communities but also because of a renewed interest by government, industry, and civil society in inter- and transdisciplinary practices. Specific areas of interest are “hard” societal problems such as health care, climate change, and sustainable development. The recent emerging of digital

manufacturing based on 3D printing and rapid prototyping has recently appeared on the national agenda and naturally intersects with the SEAD community of practice.

Networked learning environments were already evident in 2003, but their more recent evolution as online courses, blended learning, MOOCs, and other configurations has accelerated collaborative learning. Recent developments fuse formal and informal learning and promote expertise-sharing more generally, through crowdsourcing and other methodologies. In addition, "citizen science" has emerged as a focus of innovative development.

The STEM to STEAM movement to increase the role of the arts, design, and humanities in STEM strategies has acquired national visibility in the last three years. How educational communities should respond to the developments in the SEAD community is an open agenda with promising implications for broadening participation in STEM fields. The issues raised cross formal and informal learning, continuing education, and re-training; any study must bridge the silos between the different educational systems and the emerging online systems.

The SEAD White Papers report reveals that that this research community is deeply international in nature; marked by international consortia in arts and humanities that were rare ten or twenty years ago. The issues, problems, and opportunities vary in emphasis across the developed and developing world; SEAD-related work in Africa, South America, and Asia is much more prevalent that was the case in 2003. *Beyond Productivity* was carried out in a United States context. Especially given the highly collaborative nature of SEAD work, it would be opportune to provoke an international component of a new study to specifically focus on opportunities and obstacles at the international scale.

The 2003 emphasis on "creative IT" reflected the dramatic and rapid dissemination of information technologies into cultural and creative practices. Since that time, developments in the digital humanities have brought new terrains of collaborative practice into focus. One of the NSF/NEA workshops was also cosponsored by the National Endowment for the Humanities. The SEAD scope intentionally sought to cover the range of disciplines in all forms of the arts and design, but also the humanities—and this appears to be a new area of emerging opportunities.

What else has changed since 2003?

We have titled our SEAD White Papers report "Steps to an Ecology of Networked Knowledge and Innovation: Enabling new forms of collaboration among sciences, engineering, arts, and design." In 2003 and even before, it was evident that the traditional "triple helix" of innovation that linked government, industry, and academia was no longer the operative framework for the way that research and creation were being translated for societal uses. In Europe, the Creative Industries movement already captured this change to an ecology of networked actors; Richard Florida and others have popularized the concept of the Creative Class; *Beyond Productivity* addressed many of the opportunities and needs in creative neighborhoods and communities; and Brazilian digital culture programs have created new frameworks that have propelled Brazil into the forefront of SEAD activity.

Our ecological network metaphor is pertinent not only concerning the social organization of practitioners engaged in SEAD practices, but also because of the ontological organization of emerging new knowledge structures. The subtle change between conceptualizing information sharing as a "tree of knowledge" structure to a "network of knowledge" has profound implications; connections are made in different ways in trees than in evolving networks. Already anticipated by Cathy Davidson and David Goldberg in their report, "The Future of Learning Institutions in the Digital Age" (2009), it also has implications for organizational structures and funding as well as service. This means, for instance, that a national study must engage the different agencies that are stakeholders in the success of SEAD practice. *Beyond Productivity* was sponsored by the Computer Science and Telecommunications Board of the US National Research Council; a new study would necessarily engage equally the arts, design and humanities.

It seems to us important that all the actors in this emerging culture of networked knowledge make their voices heard in identifying opportunities and obstacles for SEAD perspectives and work. Their input would build on an impressive body of work represented in reports by many industry, government and civil actors who have begun identifying strategies. Reports are no substitute for action, but the periodic refreshing of the analysis and the convening of the actors are essential networked knowledge methodologies.

In some disciplines, such as the US astronomy research community, the NRC conducts "decadal surveys" to identify and reprioritize the continually evolving research and programmatic context every ten years. The SEAD White Papers report used an open call

to the international community, and we were overwhelmed by the response—with more than 200 participants, 55 detailed White Papers, and 4 in-depth meta-analyses. Our "open access" approach also provided a high degree of transparency. We can imagine using various crowdsourcing techniques in a *Beyond Productivity II* study that would allow broad participation and a diversity of conclusions.

In conclusion, the SEAD White Papers Study co-authors suggest to the SEAD network that discussions be held with interested parties on the possibility of funding a *Beyond Productivity II* report, to be carried out some 15 years after the work on the 2003 report was initiated. New opportunities and obstacles exist, and a new report would provide a timely analysis to the whole range of stakeholders who have a vested interest in enabling new forms of collaboration among the sciences, engineering, arts, and design communities. With a focus on how SEAD approaches can be applied to the critical and difficult challenges of our times, such a report would also provide an impetus to accelerate the sources of innovation and economic development that are crucial to the coming decades.

ACKNOWLEDGEMENTS

We are grateful to the many people who wrote and reviewed Abstracts, White Papers, Suggested Actions, and analyses of the body of work. Listings of these contributors appear at the end of this document. The response we received to this open international call was an overwhelming indication of the timeliness of this work. The generosity of the SEAD White Papers authors in documenting their experience and ideas is indicative of their energy, inventive spirit, and commitment to networking. We are grateful to them and thank, in particular, Pamela Jennings who initiated the SEAD and XSEAD projects during her tenure at the US NSF, and Joan Shigekawa and William O'Brien at the US NEA who have championed the need to understand the opportunities and needs of the emerging SEAD community of practice. Additional funding was provided by the ATEC program at the University of Texas at Dallas and the Institute for Applied Creativity at Texas A&M University.

Appendix 1: Suggested Actions by Action Cluster

Below are the Suggested Actions for each of the White Papers Action clusters. Author names correspond to the lead authors of the White Papers. The Suggested Action numbers correspond to numbered actions within White Papers and Abstracts.

TRANSLATING: Problem-driven connections among academic, commercial, and civil societies

1. Project formation and translational value.

   Specific suggestions include the design of products, engineering, furniture, architectural; need driven projects; societal uses and scientific inquiry.

   Authors:
   Challa 3, 4, Davis 6; Essl 1, 3; 10; Marrin 7; Miranda de Almeida 6c5, 12c1; O'Modhrain 1; Root-Bernstein 12, 13; Solar 8; Thill 5; Tisselli 1; Ox 1; Pasternak 1; Wan 1; Zilberg 1, 2.

CONVENING: Overcoming transdisciplinary thresholds

2. Conferences, workshops, camps

   Specific suggestions included "hot" topics, scouting, Environmental Sciences and ecology, STEAM, How to more fully engage the scientist community in SEAD initiatives, complexity art, digital manufacturing, biomedical, boundary fields and MOOCs.

   Authors:
   Barnes 1, 3, 4; Batson 1a; Braash 1, 2, 3; Brown 3; Delsaux 6; Jacquemin 7, 14; Marrin 1, 2, 5; Meirelles 1, 3; Ryan 2; Solar 1; Strohecker 15,18, 19; Tromble 1, 4; Wagoner 4; Williams 3.

ENABLING: Sustaining balanced SEAD relationships

3. Forming safe, productive environments for hybrid individuals and practices

   Suggestions included setting up joint appointments in art and science departments, establishing scientist residencies and expanding artist residencies.

   Authors:
   Blumenthal 2, 3, 4, 5; Cohen 1; Davis 3; Fremantle 2; Garrett 4; Jacquemin 3; Kochhar-Lindgren 2; Kuhn 4, 11; Lapointe 5; Miranda de Almeida 1a1, 1a3, 2a2, 5c4, 6c5; 16d2; Orfescu 1, 3, 4; Pampin 4, 5;

Pasternak 2; Presley 4; Quintana 2; Solar 4, 5; Strohecker 14, 21; Pampin 1, 2; Root-Bernstein 16; Ryan 2; Tseng 1; Wan 4.

INCLUDING: Spurring innovation through diversity

4. Communities addressing global issues and local solutions

This cluster includes global communities of practice, global values, ecological diversity as well as underrepresented groups and rural communities.

Authors:
Challa 6, 7, 8, 9; Garrett 1; Hankwitz 3; Jacquemin 2; Kera 3; Kuhn 10; Quintana 4; Root-Bernstein 5; Tatar 1; Thill 4; Tisselli 4; Tseng 1; Wan 1; Williams 3; Tisselli 5.

EMBEDDING: Public engagement and negotiation

5. Outreach, "citizen science," dissemination

The importance of public articulation and outreach was perceived as a many to many concept. Specific ideas include the equivalent of a "Nobel" Prize for SEAD works.

Authors:
Batson 2, 3bc; Challa 11; Cohen 2; Emmer 3; Evans 1; Jacquemin 12; Kera 2; Kuhn 10; Miranda de Almeida 1a3, 4a3, 9b3, 13c2, 17d3, 18d4; Parker 4; Pasternak 4; Quintana 1, 3; Root-Bernstein 6; Strohecker 3, 12, 20; Tisselli 2; Tromble 3; Wan 2.

SITUATING: An emerging ecology of creative places

6. "Alt spaces"

Suggested actions in this area included Wet Labs, Skunk Works, Fab Labs, Hacker Spaces, Accelerator/Incubators/drop in creativity places, as well as spaces within companies.

Authors:
Barnes 1, 2, 3, 4, 5, 6; Blumenthal 2; Delsaux 3; Garrett 2; Jacquemin 11, 14; Joy 3; Kera 1, 2; Kochhar-Lindgren 1; Kuhn 2, 4, 8, 9, 11; Miranda de Almeida 7b1; Orfescu 5; Pampin 5; Quintana 1; Parker 1, 2; Pasternak 3; Quintana 1, 4; Strohecker 13.

SENSE-MAKING: Multimodal knowledge and ways of knowing

7. Integrating understandings through the SEAD perspectives

   Among the specific topics discussed were projects authors had used to stimulate learning, particularly in K-12 environments. These included perception studies, embodied cognition, how movement (e.g., dance) aids cognitive research, and the use of code to engineer sound projects.

   Authors:
   Batson 1, 2, 3; Fishwick 3; Gresham-Lancaster 1, 2, 3; Kuhn 1, 3, 4; Ryan 1; Wagoner 4, 5; Williams 2.

DOCUMENTING: Recording and transmitting

8. Capturing, publishing, curating, archiving

   Many of the transformations underway—such as open-access publishing, multimedia and online publishing, social media, and new forms of scholarship—are accentuated because the SEAD community of practice bridges very different disciplinary cultures.

   Authors:
   Barnes 3.5; Challa 1; Cohen 2; Emmer 1, 3, 4; Essl 2; Evans 1, 2; Ferran 1; Garrett 3; Jacquemin 4, 14; Miranda de Almeida 1a7, 5c4, 15d1, 18d4; Pasternak 5; Presley 3; Strohecker 16, 17; Ryan 1; Solar 2, 3; Tromble 2, 3; Williams 3.

LEARNING: Tapping into the passion and creativity of lifelong curiosity

9. Sharing blended experiences

   Learning includes education, lifelong learning pedagogies, and evaluation methods that integrate the sciences, engineering, arts, and design.

   Authors:
   Batson 3b; Blassnigg 1; Brown 1, 2, 3, 4, 5, 6; Cenkl 1, 2, 3; Challa 5; Davis 5; Evans 3; Fishwick 1; Jacquemin 1, 6; Joy 1, 2, 3, 4, 7; Kuhn 3, 4, 5, 6, 10; Lapointe 2, 4; Marrin 3, 4; Meirelles 2; Parker 6; Pasternak 4; Presley 1, 2, 3, 4; Quintana 6; Root-Bernstein 1, 2, 3, 4, 9, 10, 11, 14, 15; Sarukkai (a) 1, 2, 3; Tatar 1; Wagoner 1, 2, 3; Williams 1, 2, 3.

COLLABORATING: Methodologies working across discipline and institutions

10. Collaborations between individuals and disciplines

    Suggestions in this area come from the ways in which SEAD practice requires individuals from differing disciplinary and organizational backgrounds to think, create, and work together.

Authors:
Barnes 4.6; Batson 3; Blassnigg 1, 2, 3, 4, 5; Blumenthal 2; Challa 3; Davis 1, 2, 4; Delsaux 1, 2, 3, 4, 5; Emmer 2; Fishwick 1, 2; Fremantle 1; Garrett 4; Gresham-Lancaster 1, 2, 3; Jacquemin 1, 10-15; Joy 5, 7; Kuhn 7; Lapointe 3; Marrin 6; Nikolov(a) 1; Miranda de Almeida 1b2, 11b5, 14Cc3; O'Modhrain 2, 3; Parker 5; Pampin 3, 4; Parker 3; Siler 1, 2, 3, 4, 5; Solar 6; Strohecker 1, 2, 11; Thill 1, 2, 3, 5; Wan 1.

11. Partnering across organizational boundaries

A wide variety of institutional structures underlies SEAD disciplines and varies internationally. SEAD collaborators pointed to the need to for agreements that could benefit SEAD partnerships.

Authors:
Jacquemin 1, 5, 8, 9, 13; Joy 5, 6, 7; Kuhn 12; Lapointe 1; Orfescu 2; Pampin 6; Parker 7; Quintana 4, 5; Ryan 2; Solar 7; Strohecker 1, 2, 4, 5, 6, 7, 8, 9, 10, 20; Thill 1, 2, 3; Tseng 1; Wan 3; Williams 3.

THRIVING: SEAD ingredients as essential contributors to healthy communities

12. Ethics and values
13. Well being and joyfulness

Actions in these sections speak of the need for SEAD methodologies to foreground, and make overt, issues of ethics and values and not defer them to secondary discussions outside of the SEAD community. Authors also mentioned that arts, design and humanities are important approaches that in themselves contribute to healthy, sustainable societies.

Authors:
Challa 2; Davis 7; Marrin 1, 2; Pampin 3, 4, 6; Parker 5; Root-Bernstein 7, 8; Ryan 1, 2; Sarukkai (a) 3; Strohecker 3; Tisselli 2, 3, 4; Wan 2.

Appendix 2: White Papers Author Key

Agrivinia, Irene, Vincentius "Venzha" Christiawan, and Deanna Herst. 2012. "Education Focus Program [EFP]: An Independent Curriculum at Grassroots Level." Abstract. http://wp.me/P2oVig-fq

Baker, Krisanne. 2012. "'How to Enable Science/Engineering to Arts & Humanities' or Conversely 'Collaborative in Spirit-Only: Keeping an Open Mind on Collaboration Across Disciplines' Or 'How to Make a Scientist Run-Like-Hell From an Artist's Collaboration Inquiries.'" Abstract. http://wp.me/P2oVig-8a

Barnes, Steven J., and Carlos Castellanos. 2012. "(Re)Structuring Innovation: Community-Based Wet Labs for Art-Science Collaborations." http://wp.me/P2oVig-nC

Barretto, Saulo Faria Almeida and Renata Piazzalunga. 2012. "The Human Project." Abstract. http://wp.me/P2oVig-c2

Batson, Glenna. 2012. "Ex-Scribing the Choreographic Mind—Dance & Neuroscience in Collaboration." http://wp.me/P2oVig-iD

Batson, Glenna. 2012. "Ex-Scribing the Choreographic Mind—Dance & Neuroscience in Collaboration." Abstract. http://wp.me/P2oVig-90

Blassnigg, Martha, and Michael Punt. 2012. "Transdisciplinarity: Challenges, Approaches and
Opportunities at the Cusp of History." http://wp.me/P2oVig-hE

Blassnigg, Martha, and Michael Punt. 2012. "Transdisciplinarity: Challenges, Approaches and Opportunities at the Cusp of History." Abstract. http://wp.me/P2oVig-8Q

Blumenthal, Marjory and Ken Goldberg. 2012. "Gathering STEAM: Bridging the Arts and Sciences to Expand Public Interest in Science, Technology, Engineering, and Math." Abstract. http://wp.me/P2oVig-fR

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Appendix 3: Abbreviations and Glossary

White Papers authors introduced the following abbreviations, acronyms, and terms in the submitted papers. Collected together, the lists shows the range of ideas and institutions involved with the SEAD mission. Institutional summaries were culled from the pertinent web page sources.

AACU: Association of American Colleges and Universities. The Association of American Colleges and Universities aims to make liberal education and inclusive excellence the foundation for institutional purpose and educational practice in higher education.

AI: Artificial Intelligence. The branch of computer science that studies intelligent systems (software, computers, robots, etc.). Researchers develop computer systems capable of performing tasks that normally require human intelligence, such as visual perception. Studies also include the scientific understanding of the mechanisms underlying thought and intelligent behavior and their embodiment in machines.

ANVUR: Agenzia Nazionale di Valutazione del Sistema Universitario e della Ricerca (National Agency for the Evaluation of the University System and Research). A public institution in Italy supervised by the Ministry of Education, University and Research (MIUR). This agency is entrusted with the following tasks: (1) execution of a program evaluation external quality assurance of the activities of universities and public research institutions and private recipients of public funds, (2) the address of the assessment activities delegated to private internal assessment of universities and research institutions, (3) assessing the efficiency and effectiveness of public financing programs and incentives for research and innovation.

ArtSciLab: Art and Science Laboratory (Santa Fe, New Mexico). A scientific, educational, and cultural nonprofit seeks to redefine the social role of art and the artist in the context of applied collaboration with focused scientific research.

ASCI: Art & Science Collaborations, Inc. Founded in 1988 as one of the first art-sci-tech member organizations in the United States. Established primarily as a network for artists who either use or are inspired by science and technology, ASCI has become a magnet for outstanding contemporary artists and for scientists and technologists wishing to collaborate.

ASN: Art, Space and Nature, Edinburgh School of Architecture and Landscape Architecture. Runs an artist-in-residence program at the British Heart Foundation Centre of Research Excellence, Queens Medical Research Institute, University of Edinburgh.

ATEC: Arts and Technology program, University of Texas, Dallas. Encourages the productive convergence of disparate fields and modes of thinking that goes beyond the lens of "multidisciplinary" or "interdisciplinary." ATEC joins science with the humanities, creativity with technology, theory with practice, and learning with research.

BHF CoRE: British Heart Foundation Centre of Research Excellence (BHF CoRE), Edinburgh. One of several research centers of the British Heart Foundation, the Edinburgh CoRE hosts an Artist in Residence program, created in 2009, that invites postgraduate artists from the Edinburgh College of Art to visit the BHF Centre of Research Excellence.

BioVis: The biology data visualization branch of bioinformatics, applied to related activities during the Institute of Electrical and Electronics Engineers' VisWeek conference. It brings together researchers from the visualization, bioinformatics, and biology communities. Its goal is to establish interdisciplinary dialogue and to promote the sharing of expertise in communities concerned with computer graphics, scientific visualization, and information visualization to different areas of the life sciences.

BRIDGES Consortium: Formed in 2001 as an international social-media network for the development and dissemination of strategies that improve and support interdisciplinary collaboration in the arts, sciences, culture, and technology.

CAA: College Art Association. Founded in 1911, the CAA promotes the visual arts and their understanding through committed practice and intellectual engagement.

CARC: Center for Advanced Research Computing, University of New Mexico. The center's mission is to enable excellence in research in science, engineering, biomedicine, humanities, and the arts through support for parallel supercomputing, large-scale informatics, and advanced visualization. It provides leadership to enhance interdisciplinary research and education at the university.

CARTAH: Center for Advanced Research Technology in the Arts and Humanities, University of Washington, Seattle. This program is no longer active. With many other digital humanities initiatives funded on the University of Washington campus CARTAH lost most of its clients, becoming obsolete.

CAST: Complex Adaptive Systems Theory. Generates research and recommendations on communities of practice, connectivism, and networked learning. This theory arose out of the specific need to understand current developments in emergent learning and to inform design for emergence in practice.

CCMB: Center for Cellular and Molecular Biology, Hyderabad, India. A biotechnology research establishment of the Council of Scientific and Industrial Research and a designated Center of Excellence for Global Molecular and Cell Biology Network.

CDASH: Curriculum Development in the Arts, Sciences and Humanities. A web-based project in conjunction with the Leonardo Education and Art Forum.
http://www.utdallas.edu/atec/cdash/

CEA: Europe-based research centers studying micro- and nanotechnologies.

CERI: Centre for Educational Research and Innovation, part of OECD. Conducts extensive research that goes beyond the formal education system and addresses learning at all ages. It emphasizes accumulating statistical evidence that demonstrates the value of its research.

CHI: Computer-Human Interaction. Involves the study, planning, and design of the interaction between people (users) and computers. Also see Human-Computer Interaction (HCI), Man–Machine Interaction (MMI).

CIRET: Centre International de Recherches et Études Transdisciplinaires International Center for Transdisciplinary Research, a nonprofit research institute located in Paris.

CNRS: Centre National de la Recherche Scientifique. French National Center for Scientific Research, a government-funded research organization, located in Paris.

CSM: Central Saint Martins. CSM is a part of the University of the Arts, London.

DIWO: Do-It-With-Others. A term created in 2006 by Marc Garrett as part of Furtherfield's collaborative project, *Rosalind*, as an extension of the term DIY.

DIY: Do-It-Yourself. The method of building, modifying, or repairing something without the aid of experts or professionals.

DXARTS: The Center for Digital Art and Experimental Media, University of Washington

EAGER. Early-concept Grants for Exploratory Research. A grant program of the National Science Foundation. EAGER grants replaced the Small Grants for Exploratory Research (SGER).

EAT:. Experiments in Art and Technology. A nonprofit organization established to develop collaborations between artists and engineers and to help develop technology-based artworks. Past participants include, among others, artists John Cage and Robert Rauschenberg and engineers Billy Klüver and Max Mathews.

EdX: A nonprofit collaboration founded by Harvard University and MIT that develops and promotes interactive learning via the World Wide Web.

EFP: Education Focus Program, Indonesia. A curriculum, part of the House of Natural Fiber (HONF) Foundation, that promotes interdisciplinary knowledge exchanges by bridging art, science and technology.

ENSAD Lab: The ENSAD research laboratory.

ENSAD: École Nationale Supérieure des Arts Décoratifs, Paris. An advanced institute of applied arts.

ERASMUS: European Community Action Scheme for the Mobility of University Students. Also known as the Erasmus Programme and the Erasmus Project,this student

exchange program is part of the European Union's Lifelong Learning Program. Each year, it allows more than 230,000 students to study abroad.

ESF: European Science Foundation. Based in Europe, ESF is committed to promoting high-quality science education and research to drive progress in research and innovation. It helps Member Organizations collaborate internationally on research programs in almost every scientific domain.

FOSS: Free and Open Source Software. FOSS applies to software that is both free software and open source.

FQRSC: Fonds Quebeçoises de Recherche Société et Culture, Quebec, Canada. Funding opportunities for postdoctoral research in Canada.

GIS: Geographic Information System. Designed to capture, store, manipulate, analyze, manage, and present all types of geographical data.

GPS: Global Positioning System. A space-based satellite navigation system that provides precise location and time information.

HACC: Humanities and Arts Computer Center, University of Washington

HCI: Human-Computer Interaction. HCI involves the study, planning, and design of the interaction between people (users) and computers. Also see Computer-Human Interaction (CHI), Man–Machine Interaction (MMI).

HONF: House Of Natural Fiber. A New Media art laboratory, founded in 1999 in Yogyakarta, Indonesia.

ICT: Information and Communication Technology. An approach that stresses the role of unified communications among technologies.

IISER: Indian Institute of Science Education and Research. Together with the related National Institute of Science Education and Research (NISER), brings together science education and research institutes in India.

IITs: Indian Institutes of Technology. A group of autonomous public engineering and management institutes in India.

IMéRA: Institut Méditerranéen de Recherches Avancées (Mediterranean Institute for Advanced Research), Marseilles. Supports cross-disciplinary collaborations and art-science residencies.

Interval Research Corporation: A Palo Alto laboratory and technology incubator founded in 1992 by Paul Allen and David Liddle, computer industry veterans. Interval has employed many well-known computer technology pioneers and new media artists.

INTR: International Network for Transdisciplinary Research.. This network, based at University of Plymouth in the United Kingdom, brings researchers together to develop methods, pedagogies, and resourcing strategies for transdisciplinary, practiced-based research.

IPTI: Instituto de Pesquisas em Tecnologia e Inovação (Research Institute on Innovation and Technology). A Brazilian center for multidisciplinary research with a focus on integrated solutions between technology and human processes.

IRCAM: Institut de Recherche et Coordination Acoustique/ Musique, Paris. A laboratory for research into music and sound sciences and technologies.

IRRODL: International Review of Research on Open and Distance Learning. A refereed, open-access e-journal that disseminates original research, theory, and best practices relating to open and distance learning worldwide.

ISEA: International Society for Electronic Art. A nonprofit organization fostering interdisciplinary academic discourse and exchange among culturally diverse organizations and individuals working with art, science, and technology. Its main activity is the annual International Symposium on Electronic Art.

ITCP: Information Technology and Creative Practices. A term introduced by the *Beyond Productivity* (Mitchell, Inouye, and Blumenthal 2003) report, which spurred the Creative-IT program at NSF.

JRP: Jogja River Project. A collaborative project involving lifepatch.org and several communities from Yogyakarta, Indonesia.

LE: Learning and Education. A SEAD focus area.

Lifepatch: Based in Yogyakarta, on Java, Indonesia, Lifepatch is an independent community-based organization that develops creative and effective applications in the fields of art, science, and technology.

LIMSI: Computer Science Laboratory for Mechanics and Engineering Sciences. A CNRS laboratory associated with Université Pierre et Marie Curie and Université Paris-Sud.

MAHI: Media Art Historians.

MEDIATE: An intelligent, immersive, multisensory, and interactive space conceived for children with severe autism.

MHRD: Ministry of Human Resource Development, India. Works with the Indian Department of School Education and Literacy and the Department of Higher Education in balancing the socioeconomic fabric of the country.

MMI: Man-Machine Interaction. MMI involves the study, planning, and design of the interaction between people (users) and computers. Also see Computer-Human Interaction (CHI), Human-Computer Interaction (HCI).

MOOC: Massive Open Online Courses. MOOCs are aimed at large-scale interactive participation and open access via the Web.

MTL: Modern Thought and Literature. Establish in 1971, at Stanford University, this interdisciplinary graduate program aims to advance the study of critical issues in the modern world.

NASA: National Aeronautics and Space Administration. The agency of the United States government responsible for the civilian space program and for aeronautics and aerospace research.

NCERT: National Council of Educational Research and Training. An organization established in 1961 by the government of India to assist and advise the central and state governments on academic matters related to school education.

NCF: National Curriculum Framework. Adopted in 2009 by the Indian National Council for Teacher Education to encourage interested parties and stakeholders to give their views on the qualitative and quantitative improvements that could be achieved in educating teachers at school, graduate, post-graduate, doctoral, and post-doctoral levels.

NISER: National Institute of Science Education and Research. Together with the related Indian Institute of Science Education and Research (IISER), brings together science education and research institutes in India.

NSEAD (UK): The National Society for Education in Art and Design. A professional association and independent trade union that serves as the leading national authority concerned with art, craft, and design across all phases of education in the United Kingdom

NSEAD (US): Network for Sciences, Engineering, Arts and Design. Established to catalyze the formation of a pilot network that promotes innovative methods for connecting and supporting this research community across academia, nonprofit organizations, industry, and funders.

NSF: National Science Foundation. A United States government agency that supports fundamental research and education in all nonmedical fields of science and engineering.

NTUA: National Taiwan University of Art. Established as the National School of Arts in 1955, NTUA has the longest history of any art institution in Taiwan, as well as the most specialized fields of study.

OECD: Organization for Economic Co-operation and Development. The OECD provides a forum in which governments can work together to share experiences and seek solutions to common problems. Its Centre for Educational Research and Innovation (CERI) does extensive research work that covers learning at all ages and goes beyond the formal education system. Specific emphasis is put on accumulating statistical evidence that demonstrates the value of its research.

PAIR: PARC's Artist-in-Residence Program. This program pairs artists who use new media with researchers who often use the same media, though in different contexts.

PARC: Palo Alto Research Center Inc. A research and development company in Palo Alto, California, formerly known as Xerox PARC, recognized for its contributions to information technology and hardware systems.

PCT: Patent Cooperation Treaty. An international patent law treaty, concluded in 1970, that provides a unified procedure for filing patent applications.

PRIN: Research Program of National Interest. Italian Committee for National Funds. The main source of (public) funding for research projects in Italy.

PTSD: Post-traumatic stress disorder. A type of anxiety disorder that can occur after a person has gone through an extreme emotional trauma that involved the threat of injury or death.

QMRI: Queen's Medical Research Institute, Edinburgh. The Institute carries out ground-breaking research and tackles a wide range of diseases at the most fundamental cellular level. It also provides facilities for high-quality interdisciplinary research in three key areas: cardiovascular science, inflammation research, and reproductive biology. QMRI initiated an artist-in-residence program in 2009 for postgraduate artists from the Edinburgh College of Art.

R & C: Research and Creation.

Rosalind: A new media art lexicon launched by Furtherfield in 2004.

RRF: Royalty Research Fund. An Office of Research program at the University of Washington that supports faculty seeking to establish new research programs. Its purpose is to advance new directions in research, particularly in disciplines for which external funding opportunities are minimal, for faculty who are junior in rank, or in cases where funding may provide unique opportunities to increase applicants' competitiveness for subsequent funding.

SACRe: Science Art Création Recherche. An innovative French doctoral program in science and the humanities that is the result of cooperation of five institutions: the Higher National Conservatory of Dramatic Art (CNSAD), National Conservatory of Music and Dance in Paris, the National School of Decorative Arts (ENSAD), the National School of Fine Arts (ENSBA), and the École Normale Superieure (ENS-Ulm).

SARC: Scientists/Artists Research Collaborations. Supports collaborations among artists and scientists. Based in New Mexico.

SEAD: Science, Engineering, Art and Design. The SEAD network is a community of advocates for the importance and value of research and creative work across the arts and sciences.

STEAD: Science, Technology, Engineering, Art, and Design. The word STEAD is also an old English word that means place.

STEAM: Science, Technology, Engineering, Art, and Mathematics.

STEM: Science, Technology, Engineering, Mathematics. This acronym is currently expanding beyond its initial use, discussing the integration of Science, Technology, Engineering, and Mathematics into a new transdisciplinary subject in schools, particularly at the K-12 level.

TAFI: Training Artists for Innovation.

TASML: Tsinghua Art Science Media Laboratory, China. The full name is the Tsinghua University Art and Science Research Center Media Laboratory.

TASML IRP: A new type of artist residency program that focuses on laboratory-inspired artistic practice. The program benefits from the rich research culture of Tsinghua's science and technology community.

THEMAS: "Technology, Humanities, Engineering, Math, Arts, and Sciences." An acronym that rearranges STEM: "Science, Technology, Engineering, and Math."

TNUA: Taipei National University of the Arts. A national university in Guandu, Beitou District, Taipei, Taiwan.

UAL: University of the Arts London (formerly the London Institute). A public research university that includes six formerly independent colleges: Camberwell College of Arts, Central Saint Martins College of Arts and Design, Chelsea College of Art and Design, London College of Communication, London College of Fashion, and Wimbledon College of Art. It offers a MA in Art and Science at Central Saint Martins.

UBEATS: Universal BioMusic Education Achievement Tier in Science. A science and music curriculum that utilizes both science and music to provide creative problem-solving activities and concept building for grades 2 and 5. A project of UNC-Greensboro (UNCG), North Carolina State University (NCSU), and the NSF.

Ubiquitous Computing: A concept for human-computer interaction in which computing is a seamless part of environments and information processing is thoroughly integrated into everyday objects and activities. Because people engage with many computational devices and systems simultaneously, they may not necessarily even be aware that they are engaging in ubiquitous computing.

UDP protocol: User Datagram Protocol. One of the core members of the Internet protocol suite (the set of network protocols used for the Internet).

VIDA: Virtuality, Interaction, Design, and Art. An Artscience thematics at LIMSI, a scientific research laboratory of the CNRS associated with the Université of Paris Sud and Université Pierre et Marie Curie.

VIZBI: Visualizing Biological Data. A community Resource for the VIZBI conference series on computer methods for visualizing biological data.

VSM: Viable System Model. A model of the organizational structure of any viable or autonomous system.

XSEAD: Virtual e**X**change to Support Networks of Creativity and Innovation among **S**cience, **E**ngineering, **A**rts and **D**esign. An online community platform for those working across disciplines: design, the arts, engineering and science. It is a home for creative works, innovative processes and explained outcomes that cut across traditional boundaries.

YASMIN: Your Art Science Mediterranean International Network. A moderated list for art-science-technology interactions around the Mediterranean Rim.

Appendix 4: Bibliography

Below is a selected bibliography comprised of sources compiled from the submitted White Papers. This resource is also available on the SEAD site: http://seadnetwork.wordpress.com/bibliography/.

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Appendix 5: Compilation of Prior Reports

Below is a selected bibliography comprised of third-party reports compiled by SEAD network. Reports that make recommendations in the SEAD context can be found on the website: http://seadnetwork.wordpress.com/reports/.

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Appendix 6: Demographics

Below we present demographic information about the total of over 200 individuals who participated in the SEAD White Papers as part of the Steering Committee, and as Coordinators, Authors or Advisors.

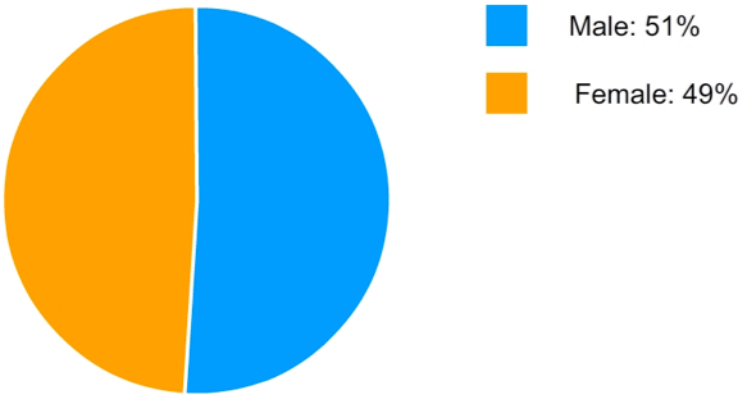
- The gender distribution is balanced, with 49 % female and 51% male participants.

- There is a predominance of participants in academic careers, with 65% in academic, and 35% in non-academic positions (business, nonprofit, government, self-employed).

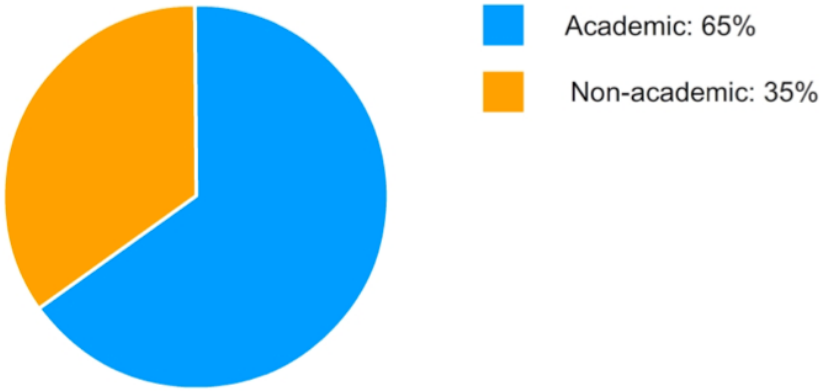
- We listed participants by degrees earned and practice area, divided into three areas: SE (Science and Engineering), AD (Art and Design including Humanities and Social Sciences), and Hybrid, for people with degrees in SE and AD, or degrees in one area and practice in the other. A majority of 64% is in the AD area, followed by 20% in Hybrid and 16% in SE.

- The geographic distribution shows a predominance of participants in the northern hemisphere, with 56% participants from North America, 26% from Europe, 7% from Asia, 6% from South America, 4% from Oceania (Australia) and 1% from Africa. There are representatives from 27 countries. The USA and UK account for approximately 75% of all participants. Australia, Canada, Netherlands and Brazil follow with approximately 10% each.

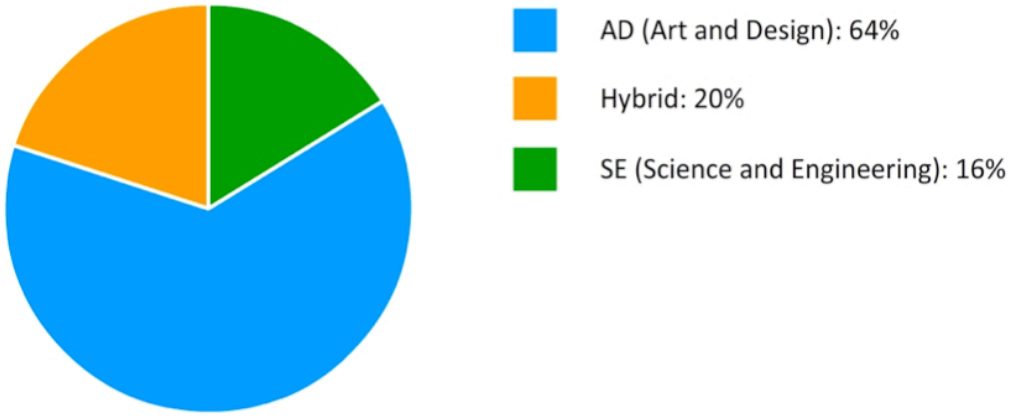
Gender



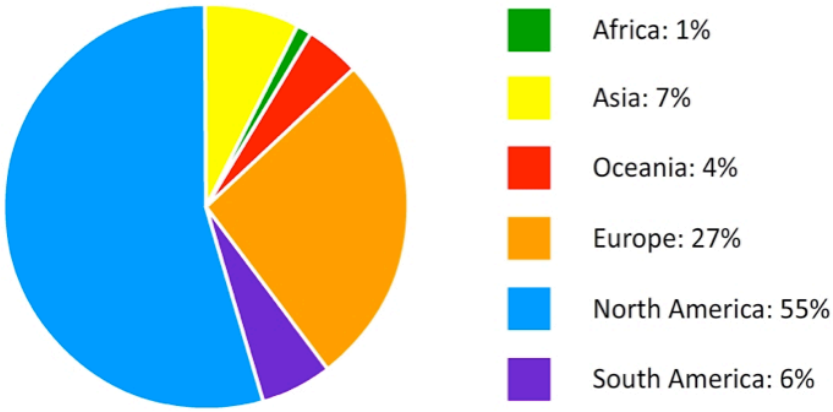
Career



Area of Practice



Geographic Distribution



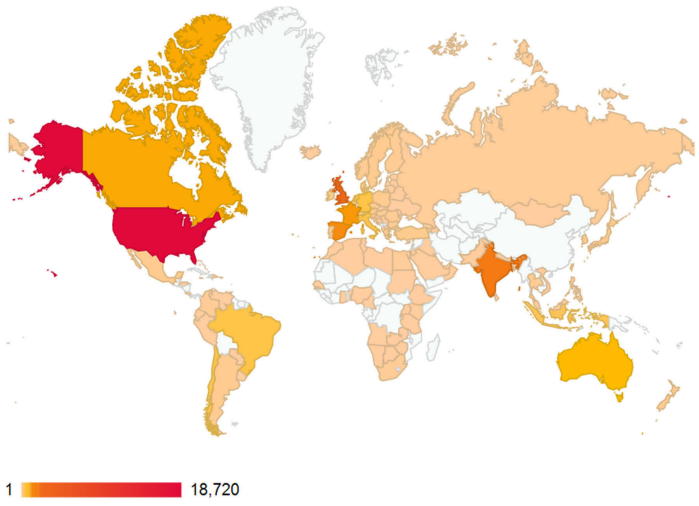
Site Visits to the SEAD White Papers site (http://seadnetwork.wordpress.com)

The statistics below offer a glimpse of SEAD participants' geographic locations.

Top Views by Country for all days ending 2013-07-09 (Summarized)

7 Days | 30 Days | Quarter | Year | All time

Country	Views
United States	18,720
United Kingdom	2,493
India	1,939
Spain	1,111
France	1,098
Canada	950
Australia	862
Hong Kong	821
Germany	472
Brazil	472
Italy	443
Chile	424
Netherlands	410
Indonesia	383
Denmark	196
Singapore	153
Belgium	135
Switzerland	122
Taiwan	116
Ireland	112
Turkey	111
Austria	103
Republic of Korea	90
Poland	90
Greece	87
Slovenia	83
Japan	82
Sweden	82
Argentina	82
Mexico	81
New Zealand	77
Portugal	68



Thailand	67
Norway	66
Hungary	66
Romania	59
Czech Republic	56
Finland	55
South Africa	51
Colombia	48
Bulgaria	45
Israel	42
Philippines	42

Croatia	29
Egypt	29
Russian Federation	26
Malaysia	25
Pakistan	18
United Arab Emirates	18
Kenya	16
Saudi Arabia	15
Serbia	14
Cyprus	14
Costa Rica	11

Appendix 7: SEAD Conferences Poll

In an informal poll, SEAD PI Carol LaFayette asked over 50 participants to list the "top 3 must attend conferences and/or must join organizations." 67 entries are listed.

1. ACM Conference on Designing Interactive Systems (ACM-DIS)
2. ACM International Confeerence on Mobile Computing and Networking (MOBICOM)
3. ACM Knowledge Discovery and Data Mining (ACM-SIGKDD)
4. ACM Multimedia Conference (ACM-MM)
5. ACM SIGCHI Conference on Human Factors in Computing Systems (CHI)
6. ACM Special Interest Group on Computer Graphics and Interactive Techniques (ACM -SIGGRAPH)
7. ACM Supercomputing (ACM-SC)
8. ACM Symposium on Principles of Programming Languages (ACM-SIGPLAN-SIGACT)
9. ACM Symposium on User Interface Software and Technology (ACM-UIST)
10. American Association for Artificial Intelligence National Conference (AAAI)
11. American Association for the Advancement of Science (AAAS)
12. American Association of Museums (AAM)
13. American Educational Research Association (AERA)
14. American Institute of Architects (AIA)
15. American Institute of Graphic Arts (AIGA)
16. American Society for Engineering Education (ASEE)
17. Ars Electronica
18. Association of Children's Museums (ACM)
19. Association of Science and Technology Centers (ASTC)
20. Association for the Advancement of Artificial Intelligence (AAAI)
21. Bridges
22. College Art Association (CAA)
23. Computer Graphics International (CGI)
24. Conference on Advanced Visual Interfaces (AVI)
25. Constructionism
26. Electronic Language International Festival (FILE)
27. European Conference on Computer Vision (ECCV)
28. Foundations of Digital Games (FDG)
29. Game Developers Conference (GDC)
30. IEEE Conference on Computer Communications (INFOCOM)
31. IEEE Conference on Computer Vision and Pattern Recognition (CVPR)
32. IEEE International Conference on Computer Vision (ICCV)
33. IEEE International Conference on Data Mining (ICDM)
34. IEEE International Conference on Multimedia and Expo (ICME)
35. IEEE International Parallel & Distributed Processing Symposium (IPDPS)
36. IEEE Symposium on Foundations of Computer Science (FOCS)
37. IndieCade
38. Inter Society for Electronic Arts (ISEA)
39. International Conference on Autonomous Agents and Multiagent Systems (AAMAS)

40. International Conference on Computer Aided Design (ICCAD)
41. International Conference on Digital Arts and New Media (ARTECH)
42. International Conference on Intelligent Systems for Molecular Biology (ISMB)
43. International Conference on Machine Learning (ICML)
44. International Conference on User Modeling, Adaptation and Personalization (UMAP)
45. International MultiConference of Engineers and Computer Scientists (IMECS)
46. International Conference on Intelligent User Interfaces (IUI)
47. Intelligent Tutoring System Conference (ITS)
48. Materials Research Society 2012 Fall Meeting & Exhibit (MRS)
49. Multimedia Modeling (MMM)
50. National Academy of Sciences (NAS)
51. National Art Education Association (NAEA)
52. National Association for Gifted Children (NAGC)
53. National Council of University Research Administrators (NCURA)
54. National Humanities Alliance (NHA)
55. National Science Teachers Association (NSTA)
56. Northern Spark
57. ReGeneration (NYSCI)
58. Sketch Based Interfaces and Modeling (SBIM)
59. Society for Literature, Science, and the Arts (SLSA)
60. South by Southwest (SXSW)
61. Sundance
62. Very Large Data Bases (VLDB)
63. Vivo Conference (VIVO)
64. World Conference on E-Learning in Corporate, Government, Healthcare & Higher Education (AACE)
65. World Congress on Engineering (WCE)
66. World Congress on Engineering and Computer Science (WCECS)
67. World-Wide Web Conference (WWW)