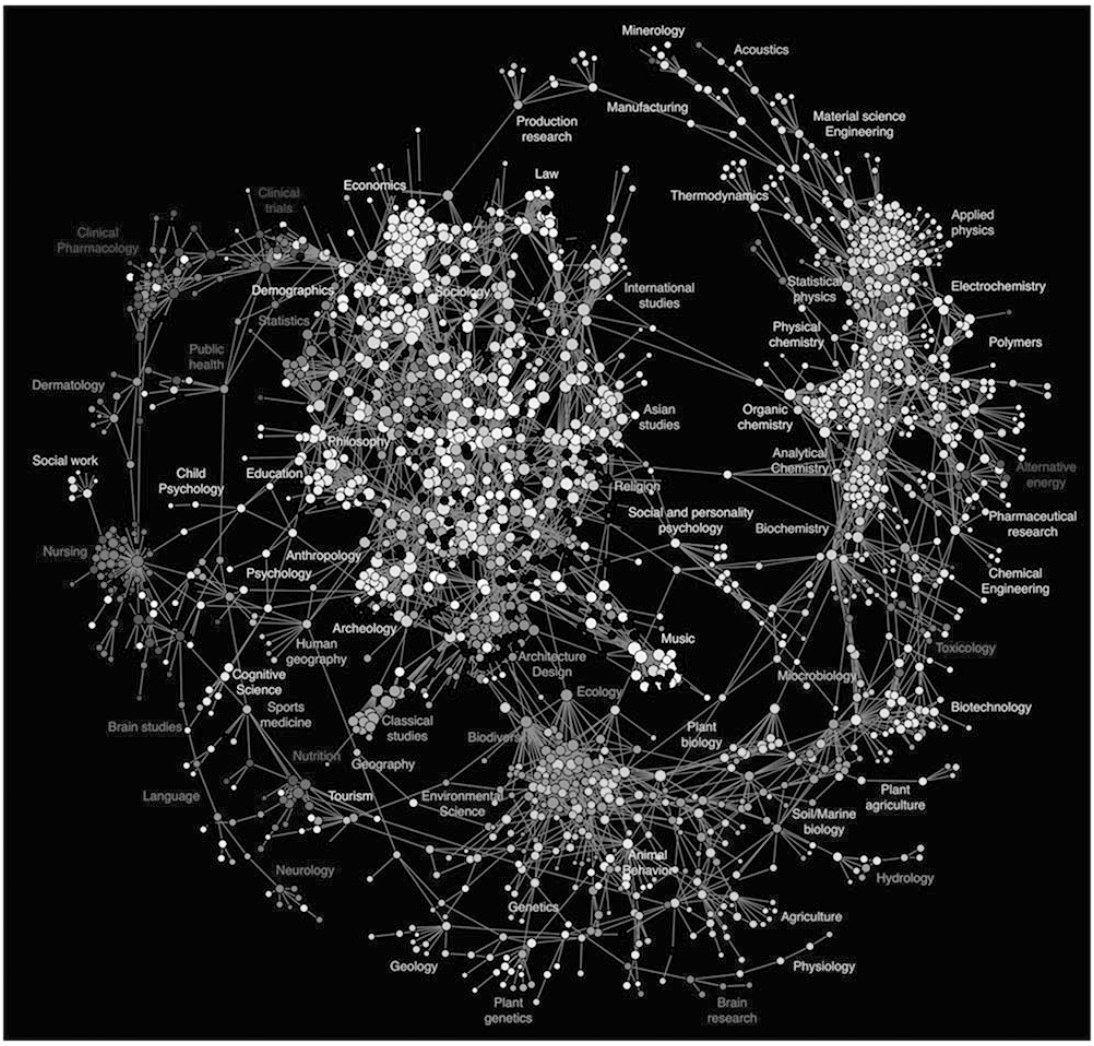
# Steps to an Ecology of Networked Knowledge and Innovation

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




DRAFT OVERVIEW OF A REPORT ON THE **SEAD** WHITE PAPERS

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

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## Steps toward realizing SEAD goals: Suggested Actions

Two separate US agencies, the National Science Foundation (NSF) and the National Endowment for the Arts (NEA), came together to support several workshops in 2010, 2011, and 2012. These initiatives resulted in concerted efforts among the diverse participants, one of which led to the NSF grants that spawned the SEAD (Sciences, Engineering, Arts, and Design) network and XSEAD portal. This consortium has been growing steadily. In late 2012 the NSF, NEH, NEA, and Microsoft Research sponsored the Media Systems workshop that emphasized computational processes as part of contemporary culture. These and other "convenings" have played an important role in bringing into focus the opportunities and obstacles facing this rapidly growing research and creative community. We are building on a multi-decade period of growth and have now reached critical mass in a number of new areas.

The SEAD network includes active professionals in the physical and social sciences, mathematics, engineering and technology, the creative arts in all their forms, design professionals, and researchers in the humanities. The SEAD acronym is an overarching name, not limited to the disciplinary referents but intended to be inclusive of the community of practice actively collaborating. An open-access website (http://sead.viz.tamu.edu/) serves the community and includes these statements of purpose and goals:

> Innovations emerging from the intersection of the sciences, engineering, arts, and design are transforming our economy, culture, and learning contexts. This transformation is emerging through products, methods, and questions that are fundamentally hybrid, such as software developed for human play, hardware designed for aesthetic elegance, and scientific and cultural information requiring new means of interpretation and expression to enable greater understanding of complex dynamics. Innovation stemming from interdisciplinary creativity is a major contributor to the development of new, sustainable economies and harmonious, cooperating societies. SEAD, the network for Sciences, Engineering, Arts, and Design, facilitates research, dialogue, and communication within and among those working in these areas.
>
> *Vision*
> We will become the leading advocate for collaboration among the sciences, engineering, arts and design, fostering innovation and learning that impact community sustainability and economic growth.

*Mission*

We operate in entrepreneurial, sustainable ways to identify and promote broader impacts for communities and individuals in new areas of practice, research and critical discourse achieving creative excellence and intellectual merit.

*Goals*

*Advocacy for culture and economic development.* The network champions partnerships that value sustainability, community development and social entrepreneurship, in order to spur economic growth.

*Advocacy for research and creative work.* The network facilitates experimentation with new methods, materials, and modes of creative inquiry and understanding in order to spawn groundbreaking discoveries and inventions.

*Advocacy for learning and education.* The network promotes lifelong learning by supporting topics, pedagogies, and evaluation methods that integrate the sciences, engineering, arts, and design.

*Advocacy for collaboration and partnership.* The network is a nexus for strategic partnerships among individuals and organizations including government, industry, civil, and academic institutions fostering initiatives that bring together diverse disciplines and domains.

In the NSF workshops leading to formation of the network, many participants had voiced the sentiment that it is time to reassess the current situation for SEAD work. Among these participants were collaborators on a 2003 US National Research Council report called ”Beyond Productivity,” chaired by the late Bill Mitchell [1]. The idea of a "Beyond Productivity II" report gained currency under the leadership of Ken Goldberg and Marjory Blumenthal, who had been one of the editors of the initial report. Sometimes referred to as “Beyond Creativity,” the SEAD White Papers initiative was born of these discussions. Chaired by Roger Malina and co-chaired by Carol Strohecker, and with the assistance of an international Steering Group, this one-year process will culminate in June 2013.

Ultimately, those gravitating toward this initiative 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. The surmise was that such a preliminary study might identify the timely need for

a new formal, national-scale report in the US – “Beyond Productivity II.” As with the original report, we are concerned with intersections of computing with the humanities, arts, and design – what the Beyond Productivity authors dub "ITCP" (Information Technology and Creative Practices). 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 homophonically characterize 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 response: some 74 abstracts, 54 full White Papers, 3 detailed meta-analyses, and 260 Suggested Actions. More than 150 individuals were involved [2].

We have also compiled a bibliography of more than 30 prior reports [3] 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. A number of new areas, however, are identified as opportunities with large communities of research and practice.

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, sometimes known 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 receiving a critical mass of the White Papers' comments and suggestions. These clusters may frame questions that specific stakeholders can use as entry points for longer-term

consideration of 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 find Suggested Actions that relate to our four framing objectives of culture and economic development, research and creative work, learning and education, and partnership and collaboration.

## ACTION CLUSTERS

**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 S-E-A-D relationships

3. Establishing safe places for hybrid individuals and practices

**INCLUDING**: Creating a dynamic, varied network

4. Global communities and local diversity

**EMBEDDING**: Public engagement and negotiation

5. Outreach, dissemination, "citizen science"

**SITUATING**: An emerging ecology of creative places

6. "Alt spaces"

**SENSE-MAKING**: Multi-modal 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. Partnerships across organizational boundaries

**THRIVING**: SEAD ingredients as essential contributors to healthy communities

12. Ethics and values
13. Well-being and joyfulness

## Action Clusters and SEAD Goals [4]

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

#### *1. Project formation and translational value*

Many White Paper authors consider working across traditional boundaries of organizations, disciplines, and sectors to be a strategy for innovation. The benefits may be social and/or economic. Authors suggest concerted action among engineers, industry members, and philanthropists, with the goal of identifying projects that may have commercial potential. In order to optimize translational value, it helps to encourage partnerships with industry early in formation of a project. Including the perspectives of marketing and use further increases the likelihood of translation for broader benefit. Authors also suggest that rather than placing the burden of trust-building on a collaboration among strangers, SEAD practitioners would do well to broaden and diversify their own networks and to identify specific strategies for translating their work. A helpful environment for this purpose is evolving steadily, including supports such as incubators, accelerators, and crowd-sourcing. As in medicine, where the methodology of "translational science" is accelerating the adoption of research for various applications in health care, so the SEAD community must develop targeted strategies for translating results with commercial viability. Some authors would like to see the mobile device industry creating means for open and free content creation that can readily exchange across platforms, to aid SEAD collaborations and translations. There are also unrealized potentials for such platforms to encourage public and student engagement with SEAD-relevant knowledge. Explicitly encouraging students to consider the transferability of their knowledge can help in leveraging skills learned in one domain toward understanding in another. For example, observation and working with patterns are two skillsets relevant in domains of both art and science, so may be

worth emphasizing in curricula. Making explicit how polymaths throughout history have applied skills and transferred knowledge across domains could also help promote learning and innovative thinking.

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## CONVENING: Overcoming transdisciplinary thresholds

### *2. Conferences, workshops, camps*

We were struck by the large number of emerging research and application topics: the SEAD community is exploring almost all areas of scientific and engineering research, from urban planning to health care to the nanosciences. Developments in the environmental sciences and ecology are highly active. There are also stated interests in visualization and big data, digital manufacturing, climate change, and sustainability. Rather than delving into specific topic areas in this study, we emphasize the importance of convening interested parties across disciplinary and organizational boundaries, in a variety of scales and formats. Often the heterogeneous communities do not meet in the same fora; for instance, scientists in separate subdisciplines who may all work with artists or designers may never meet in the same scientific conferences. The recent NSF and NEA workshops have played an important role in convening members of the SEAD community, as do groups within professional societies and the plethora of conferences, symposia, and public forums and festivals. The various gatherings can support dialogue about timely topics, facilitate scouting for collaborative partners, and engage funders in the merits and potentials of SEAD-related interest areas.

Several papers underscore the benefits of connecting artists and scientists with local communities and creating forums for mixing people from business, academic, and nonprofit organizations. Suggested venues include public events with large-scale displays; podcasts, webcasts, and other web-based forums; and "art-science cafes." The exchanges described vary in formality, from happenstance interactions to roundtable discussions and organized meetings and seminars. Some authors suggest forming a consortium of universities and art schools in an ambitious, transdisciplinary collaboration "to undertake the scholarly and visual mapping of the themes and paradigms of collaborative art, science, and technology work over the past twenty years," including evaluation of the outcomes of those works. Other authors call for compilation of a "knowledge bank" of "emergent learning" courses and curricula spanning multiple grade levels and drawing on global resources. Authors also encourage experimentation with new technologies and institution of new roles and programs, such as residency programs in community-based wet labs and hacker spaces. Some authors suggest that public receptivity to scientific topics could

become a gauge for prioritizing funds for research. Productive transdisciplinary collaboration requires a supportive infrastructure, including spaces for meetings, collaborative creativity, and dissemination vehicles. Because the SEAD community is so diverse, it needs specific convening strategies as appropriate to particular places and collaborators, as well as means to fill the gaps.

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**ENABLING**: Sustaining balanced S-E-A-D 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' or the differing disciplinary personal and institutional environments faced by different collaborators. These issues are raised in a number of the other domains for action that we have identified; for instance the "Situating" domain is concerned directly with the issue of designing work space environments that allow the differing actors to participate.

Inter-disciplinary practices within the sciences (e.g. bio-physics,) or between science and engineering (e.g. bio-informatics), or in integrative studies (environmental sciences) occur within a shared episteme of the scientific method. Many sciences can be described as techno-sciences (genomics, 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.

The SEAD goals seek to broaden such inter-disciplinary work to include the arts, design and the humanities and these 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 areas are shared by all interdisciplinary practice particularly in emerging areas. Promotion and tenure in universities is particularly problematic both because of sociological resistance but also the inability to use standard metrics (e.g. publication in established peer reviewed journals) or difficultly 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; the very fact of absence of postdoctoral funding in general 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 (the INSPIRE at NSF, the new AHRC Hubs in the UK) but there remains a generic problem of evaluation.

Other asymmetries exist when collaborators are situation in commercial or civil institutions. Such collaborators may not have what are called "terminal degrees" in the USA (e.g. a PhD or MFA) and this can create conflictual situations in terms of funding attributions (researchers in the gaming and entertainment industry often cannot be certified for teaching). We have mentioned elsewhere the stresses caused by differing IP 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 problematic than 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 problematics, but is a sociological asymmetry.

Though many of these issues face all inter-disciplinary or trans-disciplinary work, SEAD practice faces particularly obstacles because of a large variety, and depth, of asymmetries; this domain would be worthy of in depth study and elaboration of best practices for overcoming the obstacles posed.

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## INCLUDING: Creating a dynamic, varied network

### *4. Global communities and local diversity*

Our contributors emphasize that the very reasons that drive them to cross disciplinary borders also foreground the need for very broad geographical and social inclusion. There are under-represented groups on bases of culture, gender, geography, age, and skills. Authors emphasize the need to support public projects that raise awareness and the level of public discourse about science and technology, through means such as accessible data visualizations and understanding of the sensing and representational capabilities of various media technologies. Authors note that

academic programs in media literacy and media arts attract more members of minority groups than other technology-oriented programs, so supporting media-oriented programs may help to counter the persistent imbalance of students and ultimately practitioners working with new technologies. Using media-technology strategies for public communication about science and technology topics may also foster greater readiness for scientific study. There is a renewed interest in certain areas of craft, stimulated for instance by 3D printing, and increasing interest in soft materials such as thread and yarn, with related potentials for STEM learning such as computer programming and mathematical topology. Arts organizations, museums, and art magazines extending beyond elite audiences could promote more transdisciplinary collaboration and sharing of knowledge and expertise across broader demographic segments. Wider adoption of the model of the practice-based doctorate could also support SEAD collaborations. Many communities are acknowledging creative industries as an area of economic development. Global-scale networks could involve programs for graduate students to visit developing countries and conduct workshops or otherwise assist local researchers. Developing countries are benefiting from low-tech and DIY protocols and tools, such as citizen science kits. Organizers of science fairs and art shows could promote inclusion by providing fee waivers for SEAD practitioners from developing countries. Internationally ranging funders could collaborate to support SEAD projects. Greater realization of the benefits of combining art and technology will require peer review processes, policy development, and cohesive linkages among a range of community organizations. One particularly important issue is how to include a broad diversity of ages in SEAD processes; the born digital generation that is carrying many of the "alt space" approaches must be an integral part of SEAD work but also including active older professionals that work after retiring from their prior organizations must be addressed.

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**Embedding**: Public engagement and negotiation

***5. Outreach, dissemination, "citizen science"***

Authors suggest reaching out to communities not only to increase awareness, but also to actively involve the public in SEAD-related work. Means for such outreach emphasize the diversity of media needed including print publications, the Internet, documentary films, public talks, interactive seminars, and mobile media. Authors call for stronger relationships between industry and community organizations to promote development of SEAD programs for people all ages. Some authors point to benefits of "grassroots innovation," in which community members engage in participatory design of potential solutions to both local and global challenges. Community collaborators can help to develop new technologies and identify culturally appropriate

applications. One area of special interest is urban farming and related practices of e-agriculture, which extend also to rural communities. New technologies can help in explaining advances in agricultural methods, while benefiting from data that farmers send from the field. Another area gaining attention for its potentials to engage broad publics in SEAD-related creativity and concepts is that of arts and crafts. Arts and crafts is also an area in which different kinds of community-based organizations could come together to conduct programs and share materials, spaces, and other resources. New forms of data sonification continue to emerge. Dance is another interest area with special potentials for involving the public in SEAD learning and creativity, particularly as it intersects with studies among cognitive scientists and neurobiologists. Cited potentials include strategies for problem solving, mitigation of attention deficits, and therapies for Parkinson's disease. Several authors note that development of web facilities to better connect SEAD researchers and educators, and to facilitate their sharing of ideas and outcomes, would also be helpful in disseminating results to the public and engaging them as collaborators. The development of "citizen science" movements in recent years has often involved researchers from the SEAD community. This vein of activity is likely to increase in coming years. With the current federal reorganization of STEM policies, there are opportunities for innovative approaches integrating the arts, design, and humanities into STEM methodologies more thoroughly than in the past (as advocated by the STEM to STEAM movement). Our authors emphasize that the SEAD work with the larger public must be seen as an ongoing work of negotiation and not of simple communication (as emphasized by European Research Council President Helga Nowotny there is an urgent need to develop a 'socially robust science").

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## 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. Authors 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.

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**SENSE-MAKING**: Multi-modal 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 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. Many write about this from personal experience, explaining how their transdisciplinary foundation aided them as adult professionals. Specific topics include projects authors 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 [5]. Many authors advocate for such "evidence-based" approaches.

Key concerns in this 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 analysis of successful scientists and engineers highlight the role of arts avocations in their work. A prevalent interest in how the various human senses "play" together is reflected in focuses 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.

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**DOCUMENTING**: Recording and transmitting

### *8. Capturing, publishing, 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 showing it to peers and broader audiences. Several of the White Papers emphasize concerns about conservation and archiving of unstable media, of preservation of the work of pioneers in the field. Again, this concern is not specific to the SEAD area, but becomes particularly acute in the transdisciplinary context, so 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. This work addresses forms for publishing, documenting, archiving, and curating of both original works and the surrounding scholarship. It is important to note these "infrastructure" issues, 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 report "The Future Of Learning Institutions In A Digital Age" [6].

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**LEARNING**: Tapping into the passion and creativity of lifelong curiosity

### 9. Sharing blended experiences

Blended experiences transect all levels and situations of learning, formal to informal. Yet to date, learning continues to be largely defined as the acquisition of separately delivered skill and knowledge areas. In the past ten years there has been an increase in the number of higher education programs that house faculty from multiple disciplines. Some middle schools include traditionally structured arts programs to bolster Science, Technology, Engineering and Math (STEM) learning. SEAD discovered 35 charter schools in the US with the title of "STEAM Academy." Among these, the "A" is defined variously, attributed to "applied mathematics," "aeronautics," "humanities and language arts," and "arts."

There is a need for research to explore relevant theoretical frameworks. Theories of learning involve embodiment, project-based inquiry, cognitive studies, and literature about technology-based knowledge transfer. Tools to support SEAD learning, such as open-source frameworks, learning kits, and creativity support tools, have built a rich repository for researching best practices.

Some authors see SEAD learning as a dynamic system that engages people of all ages, employing multimodal and perceptual approaches alongside analytical, statistical, and computational ones. Learners creatively formulate the right critical questions to ask of new

technology, and —appropriately— then assign to computational systems the critical problems to solve.

Coalitions among private foundations, corporate entities, and learning groups have recently blossomed. Such models of collaborative networks can be extended to rural areas, to improve local economies with structures that support global outreach and collaboration.

SEAD's vision for lifelong learning brings together three important concepts for an ecological transition to 21st-century learning:

**Innovation**. Both artists and scientists are creative. The impact of collaborative engagement across SEAD areas is significant and underway in many arenas.

**Creativity**. Encouraging creativity is key to realizing the next generation of artists and scientists. The "creativity crisis," demonstrating that while IQ scores have risen, creativity scores have consistently decreased, needs to be addressed [7].

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

The SEAD network established a separate working group addressing the Learning and Education goal, who are developing a separate report.

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**COLLABORATING**: Methodologies working across disciplines and institutions

***10. Collaborations between individuals and disciplines***
***11. Partnerships across organizational boundaries***

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 also require partnering between different kinds of organizations. There is a large body of research and practice and best methods in academic, commercial, and civil contexts to accompany practices that require collaboration and partnering. We have been struck by the large 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. The work of SEAD practitioners draws on this prior body of collaboration practice, but because of the broad range of disciplines 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 publics 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 the 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 multi-national multi-discipline 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.

### *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. The demographics of our White Paper participants we were struck by other facts which 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 Paper authors point out that more singularly oriented individuals entering collaborative relationships need to maintain open-mindedness allowing for ongoing adjustments of preconceptions about partners' disciplines. Likewise, educating one's partner must be ongoing.

### *11. Partnering across organizational boundaries*

A wide variety of institutional structures underlies SEAD disciplines and 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 of the 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, solutions to which 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.

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**THRIVING**: SEAD ingredients as essential contributors to healthy communities

### *12. Ethics and values*
### *13. Well-being and joyfulness*

Many of our contributors raised concerns about the SEAD discourse both in terms of possible instrumentalisation of the arts, design and humanities but also because culture and values are often back-grounded 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 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 societal development and comparison, at the level of individuals and groups. Health professionals insist that well-being requires a combination of factors, from biological to psychological both at 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, and make overt, 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 expressions 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.

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## Concluding Remarks

This document represents a draft synthesis of the final report that will be delivered at the conclusion of the SEAD grant. “Steps to an Ecology of Networked Knowledge and Innovation” has been posted online in open access, inviting feedback and comment [8].

An initial comment is related to the four SEAD framing objectives of culture and economic development, research and creative work, learning and education, and collaboration and partnership. After reviewing the 74 Papers and Abstracts and discussing extensively, these framing areas seem to us useful ways of segmenting the overall objective of stimulating research and creation that integrate sciences, engineering, arts, and design. We encourage more detailed study and analysis that could result in enabling the actions identified.

This effort began with a call to the international community for White Papers addressing opportunities and obstacles in the SEAD community of practice. We received 260 Suggested Actions. There appear to be several areas where wide consensus exists; we have found that many of these also appear in the inventory of some 37 prior reports. 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.

We have grouped the Suggested Actions into 11 clusters, in each of which readers can find Suggested Actions proposed by multiple White Papers:

TRANSLATING: Problem-driven connections among academic, commercial, and civil societies
CONVENING: Overcoming transdisciplinary thresholds
ENABLING: Sustaining balanced S-E-A-D relationships
INCLUDING: Creating a dynamic, varied network
EMBEDDING: Public engagement and negotiation
SITUATING: An emerging ecology of creative places
SENSE-MAKING: Multi-modal knowledge and ways of knowing
DOCUMENTING: Recording and transmitting
LEARNING: Tapping into the passion and creativity of lifelong curiosity
COLLABORATING: Methodologies for working across disciplines and institutions
THRIVING: SEAD ingredients as essential contributors to healthy communities

Our overall impression is of a dynamic, vibrant, and rapidly growing area of practice. The SEAD community of practice 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 preliminary 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 report some ten years ago. This still seems a desirable goal, one that this White Papers study could serve by beginning to map the new landscape.

At the same time, many of the White Papers already sketch possible road maps in specific areas, and we encourage interested stakeholders to act. The final report will detail some of these strategies.

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.

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## 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.

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2. The White Papers, Abstracts, and Meta-analyses are available at http://wp.me/P2oVig-3b. The Suggested Actions are available at http://wp.me/P2oVig-rF. Contributor names are available at http://wp.me/P2oVig-v.

3. The prior reports are available at http://seadnetwork.wordpress.com/reports/.

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8. Please leave feedback about the draft report at http://wp.me/P2oVig-rK. We will post the final report at http://wp.me/P2oVig-3b.

## Community inputs through Abstracts and full White Papers

*Listed below are the URLs for the community inputs. Full White Papers are available at http://wp.me/P2oVig-4q. Abstracts are at http://wp.me/P2oVig-45. Authors are listed by the last name of the coordinator for the proposal. The Meta-analyses are available at http://wp.me/P2oVig-qa.*

### *Meta-analyses*

**Harp, Gabriel.** SEAD Themes and Insights Meta-Analysis. http://wp.me/P2oVig-qa

**Lapointe, François-Joseph.** A SEAD Network Analysis of White Papers. http://wp.me/P2oVig-qa

**Zilberg, Jonathan.** A SEAD White Paper Working Group Meta-Analysis. http://wp.me/P2oVig-qa

### *White Papers and Abstracts*

**Irene Agrivina.** Education Focus Program [EFP] An Independent Curriculum At Grassroots Level. http://wp.me/P2oVig-fq

**Krisanne Baker.** "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 Artists' Collaboration Inquiries." http://wp.me/P2oVig-8a

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

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

**Blassnigg, Dr. Martha.** Transdisciplinarity: Challenges, Approaches and Opportunities at the Cusp of History. http: //wp.me/P2oVig-hE

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

**Braasch, Jonas.** Creative Artificially-Intelligent Agents for the Arts: An Interdisciplinary Science-and-Arts Approach. http: //wp.me/P2oVig-lR

**Brixey, Shawn.** DXARTS : Lessons From a Decade of Hybrid Arts and Sciences Education. http://wp.me/P2oVig-c5

**Brown, Ron.** Using 'Processing' as a Stimulus for Producing STEAM. http: //wp.me/P2oVig-hL

**Cenkl, Pavel.** A New Ecology of Learning: Ecological Systems as Pedagogical Models. http: //wp.me/P2oVig-kH

**Challa, Dr. Krishna Kumari .** Science-Art Interactions in Asia with Particular Reference to India. http: //wp.me/P2oVig-jz

**Cohen, Nathan.** Bridging The Divide: Collaboration, Communication and Education in Art and Science. http: //wp.me/P2oVig-k2

**Cubitt, Sean**. Media Art History International. http://wp.me/P2oVig-aB

**Davis, Carol.** Using Smart Games and Immersive 3d Cloning Technology as a Tool for Highly Personalized and Social Contextual Interactive Learning and Teaching in All Levels of Formal, Online, Industrial And Personal Education. http://wp.me/P2oVig-dS

**Davis, Josie E.** A Case Study in IP arising in Art/Science Performance Research and Transdisciplinary Collaboration. http: //wp.me/P2oVig-mV

**de Almeida, Cristina Miranda**. Exploring a Model of Transdisciplinary Research Collaboration Based on Collective Action Theories. http: //wp.me/P2oVig-pY

**Delsaux, Jean.** From Workshop to Academic Laboratory, an Artistic Experience Of Transdisciplinarity. http: //wp.me/P2oVig-ky

**Emmer, Michele.** Interdisciplinary Courses, Positions, PhD, In Italy. http: //wp.me/P2oVig-js

**Essl, Georg.** Between Barriers and Prospects: Merging Art Performance and Engineering in Mobile Music Education and Research. http: //wp.me/P2oVig-ni

**Evans, Kathryn.,** Breaking Down the Silos: Curriculum Development as a Tool for Crossing Disciplines in the Arts, Sciences and Humanities. http: //wp.me/P2oVig-kp

**Fantauzzacoffin, Jill.** A Digital Arts Community Within HCI. http://wp.me/P2oVig-dU

**Fantauzzacoffin, Jill.** An Integrated Art and Engineering Undergraduate Course. http://wp.me/P2oVig-dW

**Fantauzzacoffin, Jill.** From Installation to Innovation. http://wp.me/P2oVig-dZ

**Faria, Saulo; Barretto, Almeida.** The Human Project. http://wp.me/P2oVig-c2

**Ferran, Bronac.** SEAD: From Success to Succession. http: //wp.me/P2oVig-ot

**Ferran, Bronac; Fonseca, Felipe.** The Landscape of Stead in Brazil and the United Kingdom: A Comparative Study. http://wp.me/P2oVig-fa

**Fishwick, P.** Learning Computing Through Game Experiences. http: //wp.me/P2oVig-hP

**Fonseca, Felipe.** Anti-Disciplinary Collaboration. http://wp.me/P2oVig-eM

**Fremantle, Chris.** CoRE Challenges: The artist in Residence Programme at the British Heart Foundation Centre for Research Excellence, Queens Medical Research Institute, University of Edinburgh. http: //wp.me/P2oVig-n2

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**Gresham-Lancaster, Scot.** Data Sonification: An Emerging Opportunity for Graduate Music/Sound Design Departments to Expand Research in an Art and Science Collaboration. http: //wp.me/P2oVig-hZ

**Hankwitz, Molly.** Environmental Equity: Enabling Excellence in Media Art and Science in Under-Served Communities. http: //wp.me/P2oVig-ke

**Jacquemin, Christian.** Emergence of New Institutions for Art-Science Collaboration in France and Comparison of their Features with those of a Longer Established One. http: //wp.me/P2oVig-k8

**Joy, Anu**. Mapping Space: Introducing Geographical Information Systems in Indian School Classrooms. http: //wp.me/P2oVig-i5

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**Kuhn, Sarah**. Thinking with Things: Feeling Your Way into STEM. http: //wp.me/P2oVig-l5

**Lapointe, François-Joseph**. How I Became an Art[Scient]ist: A Tale of Paradisciplinarity. http: //wp.me/P2oVig-kC

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**Nadasdy, Philip.** Complex Contemporary Art Organizations: New Transdisciplinary Models. http://wp.me/P2oVig-d7

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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