This paper was presented at The XXVIII ISPIM Innovation Conference – Composing the Innovation Symphony, Austria, Vienna on 18-21 June 2017. The publication is available to ISPIM members at www.ispim.org.

Innovation Opportunities Emerging from Leading-Edge Art/Science/Technology Interaction

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Abstract: This paper examines results from recent initiatives (FEAT) in the area of art/science/technology interaction. We study cases of artistic residencies with research projects in the area of future and emerging technologies. The results show that artistic interaction with scientists and engineers can lead to new forms of impact for technology-oriented research projects with important long-term effects in public relation of research projects by means of the materiality of artworks. In addition, artists become early adopters of technology based on their acquisition of new competencies and experimentation with research technology. The results from our analysis also indicate a long-term effect on the social networks of both artists and researchers and suggest durable collaboration emerging from longer-term artistic residencies in technoscientific research projects.

Keywords: art, science, philosophy, creativity, ethics, future and emerging technologies.

1 Art and technological innovation

Introduction

Recently, programmes in the arts, in science, and to a limited extent in technology include actions targeting the interaction of artists with research projects. A recent example is the European Commission's STARTS initiative that encourages synergies between the arts and innovation for technology and society by promoting the inclusion of artists in Horizon 2020 projects. Their aim is to increase the impact of scientific work, foster new ways of thinking, and stimulate innovation emerging from art/science cooperation. Although there have been experiments in art/science collaboration for several decades, there were only few systematic funding programmes of art/science activities in the area of technological research. In this paper, we present results from the interaction of artists with long-term science and leading-edge technology projects and its potential for innovation. These interactions were part of the FEAT project[1] ("Future

[1] www.feat-art.eu

Emerging Art and Technology") funded in the context of the "Future and Emerging Technologies" program of the EU. The FET programme – and in particular its bottom-up scheme FET Open – is an interesting funding initiative as it aims at early stage technological research. This means the projects are usually of a long-term nature and close to basic research, but at the same time still targeting novel technologies and applications.

From the point of view of research and innovation management, such longer-term initiatives provide significant challenges, for example regarding public relation and technology take-up and innovation. It is often difficult to directly connect the more fundamental research activities to the final innovation targets of the research projects. This makes the projects notoriously hard to communicate to broader audiences. In addition, the precise innovation arising from FET research activities is usually not clear from the beginning. The projects have a technological aim, but due to their early stage there usually are many directions that new services and products could take. Technologies resulting from FET are often still immature and their take up in new products and services a challenge.

The core idea of FEAT was to pair experienced artists with a set of FET projects hoping to facilitate the communication of leading-edge research and technology with a broad public and to stimulate technology take-up and ultimately innovation.

Art/science interaction for innovation

Art showing a creative interest in new technologies is not new. In fact, it may be argued that the arts and techno-sciences originated as one common field of practice and knowledge. Due to increasing specialisation in the 19th century, art, science, and technology were separated. In a rapidly growing technological society and vast interest of the arts in technological and scientific developments, the interaction of these disciplines has re-emerged, mainly after WWII. Science and technology have become the new canvasses and new spaces for artistic expression and representation. In particular, with the coming of the Internet in the early 1990's, not only the distribution and democratisation of artworks happened, but more than that, technology and its development became widely perceived as a creative process, and as a new diversification of the artistic canvas. This not only resulted in new forms of art, but also in new discourses, in particular in the arts world. Art and creativity using new media and technologies as a way of expression also led to the innovation of those same technologies. Often, artists are among the earliest adopters of new techniques when striving to create interesting works of art. This also suggests that artists have a vital role to play in research- and technology-based innovation.

Recent studies (Girão et al. 2015) show that there may be good potential for dialogue and practical collaborations between artists or creative practitioners and researchers. However, there is today an insufficient understanding of how these interactions work, what recommendable practices are, and how to best support innovation processes. This is particularly true for the combination of more basic research with early-stage technology development targeted in FET. Research reported in this paper aims to describe experiences and recommendable practices particularly in the light of effects of the art-science collaboration on stimulating creativity, technology take-up, and innovation.

Previous work

In the 1990ies the Xerox Palo Alto Research Center (PARC) adopted an interdisciplinary program to stimulate innovation from interaction with the arts (Harris 1994). However, innovation in this program mostly meant scientific novelty rather than market application. Art/science interactions have been studied for quite some time, although it is perhaps fair to say that the interest in the arts world has been much larger than in innovation research. Wilson (2002) analysed not only similarities between arts, science, and to a limited extent, technology, but also studied conditions of productive art/science collaboration. This includes the need for artists to adopt scientific competencies. More recently, the terms artistic research and research creation are used to emphasize the knowledge-aspects of creative artistic inquiry including inquiries in the realm of science and new technologies (Brandstetter 2013).

Weisberg (2006) studied creativity as a key process in science, technology and the arts, but with little practical conclusions about their interaction. A few studies focus on the aspect of creativity and innovation, i.e. the role that artistic interaction with science plays to stimulate ideation. For example, Root-Bernstein (2003) described the role that science fiction plays in driving scientific invention and enterprise innovation, but also how artists become inventors in the course of experimenting with new technologies. He argues that "art fosters science", but precisely *how* this happens is still a matter of research and debate. Based on extensive ethnography, Salter (2015) described the role of artistic experimentation at the interface to science for what has been termed research-creation. Another aspect of art/science cooperation is the social role of artists. Carayannis and Campbell (2010) use the triple helix model and expand it towards a quadruple (and quintuple) helix to include societal (and ecological) context. It may be concluded from more general works about creativity in innovation that the interaction of scientists and artists provides an environment conducive to ideation as the presence of artists results in interdisciplinary teams (Reiter-Palmon et al. 2013, Goodman & Dingli 2013). These accounts usually assume that team members directly collaborate. However, artists in residencies with science projects may only collaborate indirectly as they pursue their own artistic project.

In summary, the interaction of artists with early stage research projects has been the subject of some research in particular from the point of view of creativity and ideation in science and the arts. There is however a lack of theoretical underpinning and there is a clear lack of evidence from long-term technoscientific projects that have both a basic research and technology orientation.

2 Objectives and methodology

Objectives

This paper aims to improve our understanding of art, science, and technology interaction with a particular focus on emerging early-stage technologies and innovation. The analysis was based on the experiences gained from residencies of experienced artists at long-term leading-edge technology development and science. The results aim to provide

recommendations for the design of future art and science residencies, at the programme or at the project level.

Residencies

The FEAT project supported six funded residencies of experienced artists and initiated two more residencies without financial support from FEAT. The artists were tasked with delivering artworks after a period of about nine months during which they visited one or several research sites, e.g. laboratories. Often the scientists dedicated special attention to the presence of the artist, e.g. by organising workshops or dedicating a full day of discussion between the artists in residence and the scientists and engineers working on the project. The FET technology projects covered areas as diverse as robotics, synthetic biology, quantum physics, chemistry, and supercomputing.

For example, the project nuclock studies the transitions from an isotope of the element thorium-229 to its excited isomer state in order to – in the long run - use its energy difference to define the second with an extremely high resolution. This could result in novel clocks that are 100 times more precise than atomic clocks today. Another project, DIACAT, aims to develop a completely new technology for the direct photocatalytic conversion of CO2 into fine chemicals and fuels using visible light. subCULTron are developing a culture of robots designed to live in challenging, human polluted environments, where they will collect data and monitor their surroundings (Parsons 2016).

The selection of artists was based on an open call to which more than 250 artists from all over the world applied with a motivation letter, a portfolio, and CV. After selection of the artists, we organized a workshop were 18 FET projects presented their project, the project objectives and consortia. We then paired the artists with the FET projects based on the choices of the artists. Following selection, the artists worked in close collaboration with the scientists and engineers, for example by co-developing artworks at the different research labs.

Methodology

Although the artistic interaction with scientists is central to the project, this interaction is not pursued solely as an artistic endeavour. Our interest in the FEAT project was to make technology project results visible with other audiences including innovators, research managers, and citizens and to stimulate innovation through trans- and cross-disciplinary approaches and take-up of those results. Another objective is to study the impact of artistic collaboration on the researchers.

We studied the art-science interaction based on interviews with artists and scientists in public and internal workshops, interviews with the artists, and based on articles that the artists prepared. In a few cases, also the lead scientists provided a written account. We also organized public workshops at large art/science events with the aim to understand the interaction, recommendable practices, but also the innovation potential emerging from the artists' contributions.

Over the course of the project, a workshop at the start of the residencies helped to clarify expectations from the art/science interaction from both sides. Another workshop about halfway through the residency addressed practical questions and first experiences from the collaboration. We performed interviews with the artists after about five months.

In addition, the artists prepared papers for Leonardo detailing their experiences and their plans for the works of art. At the final exhibition, dedicated interviews with the artists collected experiences about the project set-up, about the artist's experiences, their interpretation of their own artworks, and their opinion about the impact on the work of the scientists and engineers. The interviews were transcribed and later analysed. We also fed back results from the analysis to selected researchers and artists to improve our understanding of the process and the artists' considerations in their creative process.

3 Outcomes and results

Artworks

The artworks created during the residencies all have a strong visual element and are computer graphic simulations with and without sound, installations, sculptural pieces, or take the form of an experiment decontextualized from its usual laboratory setting. For example, artist Anna Dumitriu who collaborated with the synthetic biology project created a piece entitled "Make Do and Mend". The piece refers to the first use of penicillin on a human patient in 1941. It takes the form of an altered antique wartime dress with the mark CC41, which means it was rationed utility wear – literally "controlled commodity 1941".

Figure 1 Detail of Anna Dumitriu's installation *Make Do and Mend*. The central piece is a wartime dress that was a controlled commodity during the war (CC41). The holes and stains in the old dress are patched with silk. This silk has had E. coli bacteria grown onto it using a dye-containing growth medium. See text for details.

The holes and stains in the old dress are patched with silk that has had E. coli bacteria grown onto it using chromogenic agar. The artist edited the genomes of the bacteria using a cutting-edge technique called CRISPR to remove an antibiotic resistance gene

accompanied by homologous recombination to scarlessly repair the break with a fragment of DNA encoding the phrase "Make Do and Mend".

A possible interpretation of this work is that it literally patches or 'repairs' the bacterium similar to the dress being patched with the cloth. It points to the serious issue of antibiotics requiring far more control as a commodity. The repair fragment of the DNA inserted into the genome of the bacteria says "Make Do and Mend" in ASCII code. Furthermore, the work asks, if new technologies will enable us to 'mend' issues that past scientific innovations have inadvertently created. The artist insists that the piece does not suggest a practical solution to the problem of antibiotic resistance. Rather we should regard it as a poetic statement that challenges our thinking about past technological glitches.

Table 1 presents an overview of the artworks used for the analysis in this study.

Table 1 Results from FEAT residencies after 9 months

Artist	*FET project*	*Realization of artwork*	*Issues, central concepts*
Anna Dumitriu	MRG-Grammar (gene regulation)	Wartime dress patched containing traces of genetically modified microbes	Make do and mend. Antibiotic resistance, control of commodity
Semiconductor	QuProCS (quantum simulation, quantum computing)	Simulation and visualization of sine waves	Language used to describe quantum phenomena
Boredomresearch	subCULTron (underwater robots)	Simulated and real robots	Vulnerability, emergent behaviour
Spela & Miha	INTERTWINE, Mango (exascale computing)	Art machine installation: a web of inputs, interpretation etc.	Meaning, semantics, interpretation
Evelina & Dmitry	RySQ (quantum simulators)	Electromagnetic levitation	Aesthetics of scientific experiments, stripping science from theory
Pinar Yoldas	DIACAT (catalytic CO2 conversion)	Computer generated video	Diamond's properties to transfer electrons
Kerstin Ergenzinger	nuclock (thorium 229-based atomic clock)	Drum sculpture, sonification	Noise and precision

Results indicate that the collaboration of artists with leading-edge technology development and research projects in the form of longer-term residences is a viable way of creating high-quality artworks that in turn stimulate new forms of impact for these projects. Artists not only create advanced and stimulating works of art, but there are impacts also on the work of researchers and on the competencies of the artists. In the following, we report about experiences from the residencies with an impact on effects of the residencies on the collaboration, on aspects of creativity and ideation, and on opportunities for public relation that emerge from the physical artworks. For a first analysis of the effects of the artistic residencies on the research subjects and on ethical aspects we refert to (Prem, forthcoming).

Effect of the extended residency on collaboration

The longer-term residencies reported here led to much deeper interactions than previously studied short-term collaborations. This is indicated by mutual invitations to collaborate even after the end of the funded residency and beyond the duration of the FEAT initiative. This is particularly important for the in-depth involvement of scientists and engineers. Based on the feedback from artists and scientists, the research projects are not mere suppliers of "inspiring environments". Quite to the contrary, the scientists developed a sense of collaboration with the artists despite of the fact that the artists usually had their own project, i.e. the creation of a work of art.

It remains a significant challenge to involve engineers and scientists in art/science collaborations: while artists are used to working in inter- and transdisciplinary environments, scientists and engineers are significantly constrained by professional work environments and typically unexperienced in working with artists. Longer-term relations help overcome this issue.

The artists considered the development of a trusted relationship particularly important and said that the longer-term residencies clearly supported this development. In addition, the fact that the projects were in their early phases also helped with developing confidence. Such a trustful relationship is of high practical relevance for the work process, as the artists require access to data, software, tools, instruments etc.

- FEAT's long-term residencies led to longer-lasting interactions beyond just the single residency. This is indicated by mutual follow-up invitations to collaborate and a shift in the personal networks of the researchers and the artists.
- In several cases (but not all), the artists reported that scientists remained rather reserved at first, but quickly overcame their reservation and developed a sense of joint belonging and shared objectives, i.e. the idea that both parties worked on the same goal.

Effect of the artworks on public relation

The creation of material works has a key role in disseminating the results from the interaction. The pieces transgress the traditional formal communication limits of scientific publishing that focus almost entirely on rationalizations. Observers of the pieces and performances create a more immediate and emotional stance towards artworks that can be instrumental for reaching out to specific audiences. For example, Anna Dumitriu reported how the wartime dress created an opportunity for women and in particular elderly women to almost instantly develop a connection with the artwork. Such connection may then lead to discussions and reflections about the underlying conceptual work of the artist and the scientist.

Another important point is that the artworks have a potential to catalyse continued media interest and opportunities for longer-term attention. Again, their materiality affords repeated and long-term physical presence, for example in exhibitions, at workshops, or in public spaces, offices and laboratories.

- The materiality of the artefacts creates opportunities for involving and connecting with new audiences.
- The materiality and re-contextualization may achieve a more emotional confrontation with science, i.e. reducing fear of the unknown based on the artistic transformation to commonplace material.
- Artworks (artists) received invitations to various workshops, conferences, and exhibitions. It is possible that this will continue for several years. There were requests for permanent installation of selected artworks in public spaces. However, this also requires a process of curation and contextualization.
- The events presenting art/science art range from non-science environments such as art galleries to scientific contexts (universities and research labs) or museums and public spaces. Usually, the same artwork may be shown in very different contexts and to different audiences.
- As a concrete impact from the interactions, scientists expanded their networks beyond the usual scientific community thus significantly reaching out to new audiences as a source of input.

Effect of the artworks on creativity and ideation

The arts, by their pure investigative nature can initiate innovations that are further developed by other actors because artists may not have an interest in innovation as such. Instead, they may aim to produce 'meaning'. In this way, artists play a central role not just in designing potential forms of usage of new technologies, but focus on the deeper questions of giving meaning to technology. This can result in considering social impacts, much along the lines of (Carayannis & Campbell 2010). Some artists have also proven extremely forward-looking in their experimentation with emerging technologies. Artist Pinar Yoldas, for example, proposed having models of urban environments where the new DIACAT technologies could be implemented. We may interpret this as an element of science fiction as suggested by Root-Bernstein (2003).

A key impact of involving artists in research is the ongoing questioning of even the most basic assumptions and of scientists' intentions. An important element in this context is the fact that the mere presence of the artists and the interaction with them during the project works facilitates discussions that would not usually take place in the tight timeframes of RTDI projects and their narrowly defined foci. In the case of the robotic project, artists report that scientists have appreciated the playful freedom to explore ideas that is often lost with scientific frameworks. Artists also performed entirely new experiments in novel lab set-ups that the artists helped to create. Similarly, in the context of the quantum physics projects, the artists gratefully acknowledge how the interaction with the artists facilitated processes of philosophical discussions that they usually avoid in their work.

- Scientists reported how the interaction with artists liberated scientists and engineers from their daily lab routine, permitted a fresh look at their own work, and allowed to devote explicit time for less goal-focused deliberation that is usually difficult to achieve given project deadlines.

- Early adoption of new technologies: artists acquired new competencies in scientific techniques which they later use in creating works of art.
- The artists are often fascinated by new materials and become early users of emerging technologies in ways that were not predicted by those first developing the technologies. These creations may directly feedback into scientific and technological processes when scientists and engineers use the artist's experimental set-ups for their research work.
- Ideation for scientists – from very concrete ideas for new processes to a general role of the artists as agents provocateurs.

It also is important to note non-results of the residencies. We did not see any determination to explain scientific results in the narrow sense of science communication. I.e. despite of the fact that the artworks naturally refer to the research work and results or objectives of research, they do not simply aim to explicate scientific processes to non-professionals. Quite to the contrary, several of the works take a step back from traditional rationalization and explanation in an effort to strip scientific experiments from linguistic and theoretical scaffolding and enable a direct, more emotional connection with what the scientists called the mystery of science.

In addition, we did not see any suggestions of potential (economic) application, i.e. straightforward innovation. For the case of FET projects this is unsurprising as they are relatively long-term and have time-to-market horizons often well beyond a 10-year period.

4 Conclusion

Limitations

The study of art/science interaction is naturally open to interpretation, in particular regarding the precise meaning of the artworks. In this study, we mostly focus on the accounts of the artists and to a lesser extent on experiences of the scientists. A more impact-related analysis of the residencies and their impact on the FET projects will only be possible after the end of the corresponding research work and perhaps even later when the corresponding technologies have matured.

Another limitation arises from the fact that we selected only artists with previous experience in art/science interaction. The results should therefore not be easily generalized to less experienced artists who may require different kinds of support and different timeframes. It is particularly important to keep in mind the special character of the FET programme which is highly competitive and positioned at the intersection of basic science and leading edge technological research.

Preliminary recommendations

Based on our observations and feedback from the artists, we can give the following recommendations for artistic residencies at leading-edge science and technology projects:

- The six to nine-month residency worked very well in conjunction with the artists' early involvement in the project. If anything, the artists would like to collaborate over longer periods of time and from the project onset (or even at research proposal preparation stage).
- It is recommendable to present results at a defined deadline, even if this means showing work in progress or not completely finished artwork.
- Invest in the development of trusted relationships between artists and scientists. A practical means for achieving this are dedicated one-day workshops between the artists and scientists that include presentations from both sides and extended periods of discussion.
- Costs for artists are very moderate, but sufficient budget for travel and transportation of artworks is important to ensure proper exploitation of follow-up opportunities such as invitations to conferences and exhibitions.
- Logistic and other curator-type support for artists (and to a lesser degree scientists) is important. The artists welcomed the effort at project level to reduce the overhead for the artists, e.g. organisation of event locations, contracts, or public relation activities. This meant that the artists could focus almost entirely on the interaction with researchers and the creative process and did not have to invest a lot of time in PR or organisational activities which can be complex in art/science set-ups.
- Curation of the artwork is key, even after the project. The artworks require a certain amount of explanation, contextualisation and therefore curation to ensure a proper understanding after the end of the residency.
- Facilitate systematic expansion of artists' topic and technique portfolio. The acquisition of new competencies is important for their experimentation. Therefore, it is key to support the artists in hands-on experimentation with new instruments, materials, techniques etc. This needs to be considered from the start of the residency due to the involved logistic and often even regulatory challenges.

In the case of the FEAT initiative, it was particularly useful to have a group of artists rather than a single individual residency. This supported the process with a sense of belonging among the artists, shared interest and also mutual recognition. We also believe that it is easier for a group of artists and/or artworks to create strong impact than just for a single piece or artist.

Outlook

Art/science/technology interactions will be increasingly relevant for research policy makers and research programme managers looking for novel ways to create impact from research. Given the increasing interest from broader audiences (e.g. evidenced in growing numbers of visitors to electronic arts festivals etc.) the strong interest already existing in the arts community will persist. Increasingly, innovation managers from both industry and universities take interest in the outcomes from art/science interactions. This paper provides insights into some of the challenges, describes what worked well and recommends how to best approach artists and scientists. While there may not quick wins

in the form of immediate innovation there are significant impacts on public relation, on ways of collaboration, on ideation and self-reflection that are likely to also impact on research outcomes and, ultimately, technology take-up and innovation.

Acknowledgement

FEAT was an initiative of eutema GmbH (AT), Stichting Waag Society (NL), and youris.com (BE). It has received funding from the European Union's Horizon 2020 research and innovation programme (FET OPEN) under grant agreement No 686527 (H2020-FETOPEN-2015-CSA). The author also acknowledges useful criticism of anonymous evaluators.

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