July, 2014

Narrative visualization of the outcomes of Federal investments in research

Diana Hicks, *Georgia Institute of Technology - Main Campus*

Using narrative visualization to communicate the outcomes of Federal research

Diana Hicks[1*], Tony Breitzman[2], Richard Cardona[3], Sanjay Arora[1], Bill Valdez[4]

[1] School of Public Policy, Georgia Institute of Technology, Atlanta GA, 30332-0345

[2] 1790 Analytics, Haddonfield, NJ 08033

[3] Hypno Design, Moorestown, NJ 08057

[4] US Department of Energy, Washington, DC, 20585

*Corresponding author – dhicks@gatech.edu, phone: 404 385 6015, fax: 404 385 0504

Keywords:

patent bibliometrics

narrative visualization

research outcome

communication

evaluation use

February 2014

Abstract

We offer here a narrative visualization entitled: *Technology hot spots and the Office of Science* and position its contribution within discussion of novel forms of communicating research results as an aid to maximizing use of research evaluation. In this study, patent co-citation analysis was used to systematically identify emerging high impact technologies in the US technology ecosystem and then to establish that Office of Science of the US Department of Energy (DOE) funds research that underpins these technology "hot spots." We discuss the strengths and weaknesses of this novel form of communicating evaluation results based our experience.

Funding

This project was supported by the Office of Science, Department of Energy under project number [DE-FG02-01ER30316] as well as the former Advanced Technology Program of the National Institute of Standards and Technology.

1. Introduction

Disappointing uptake of evaluation results has concerned the evaluation community for several decades. Thinking about the problem of getting evaluation results used has led evaluators to investigate factors that correlate with use (Teirlinck et al., 2013), to expand their perspective on what counts as use and to encourage participatory evaluation to induce stakeholder engagement. Though somewhat lower in profile, communication requires attention from those committed to maximizing use of their evaluation results (Shulha & Cousins, Weiss, 1997). Effective communication intertwines with other factors effecting evaluation use by, for example, engaging stakeholders too busy to participate in the evaluation itself. Weiss ends her landmark discussion of evaluation use like this:

> *The evaluator has to seek many routes to communication – through conferences, workshops, professional media, mass media, think tanks, clearinghouses, interest groups, policy networks, - whatever it takes to get important findings into circulation. And then we have to keep our fingers crossed that audiences pay attention.*

Since Weiss wrote, the discussion of evaluation use has continued, with communication remaining an afterthought. In 2007 Lawrenz et al. searched for articles focusing on dissemination as a pathway to use and found much in the way of "and the results were disseminated" but few to no articles whose topic was dissemination itself. They fill this gap with their article "Dissemination: Handmaiden to Evaluation Use" in which they compare the strengths and weaknesses of several methods of dissemination. Even the book *Evaluation Strategies for Communicating and Reporting* is seen as exemplifying evaluation as change consulting maximizing organizational learning rather than the foundation of the study of communication for maximizing use (Torres, Preskill & Piontek, 2005, cited in Shulha & Cousins, 1997).

Arguably, the communication problem has become if anything more urgent. In many areas, methods and data have become more sophisticated, meaning the substance of what needs to be conveyed is more arcane and more difficult for stakeholders to understand. Anne-Marie Slaughter, former dean of Princeton's Woodrow Wilson School of Public and International Affairs was recently quoted in a Washington Post blog saying the research coming out of public policy schools is "less and less accessible to the lay reader. The jargon has become more and more specialized" (Piereson and Riley, 2013). As the Post notes, if policymakers can't understand policy school research, what can professors hope to accomplish? Evaluation, as part of the broader enterprise of public policy research, partakes of these problems.

In comparison with evaluation of education or social programs, research evaluation has been less engaged with broader audiences. This parallels the larger science and technology policy arena, which in the U.S. benefits from broad public and political support but often fails to stimulate active interest, input, and understanding from the general public (Neal et al., 2008, p. 400; Morgan and Peha, 2003). The engagement problem is further compounded by an exclusive discourse that often restricts the dissemination of evaluation results. Commissioning stakeholders as well as those evaluated tend to share advanced educational backgrounds and a vocabulary, as well both are familiar with the programs evaluated, evaluation methods and results. This simplifies the communication task as evaluators can discuss results with stakeholders and with each other in much the same way (Torres, Preskill & Piontek, 2005, p. 18). Thus communication methods have not merited much attention. However, the increasing emphasis on achieving broader societal impacts from research suggests an increasing need to communicate and justify the value of research to broader societal groups. Communicating with diverse audiences presents difficulties whose solution will require more explicit attention to and valuing of varied communication strategies to meet the different needs of different audiences (Torres, Preskill & Piontek, 2005, pp. 264-5).

Partly in response to these issues, novel forms of communicating evaluation results are beginning to gain attention (MacNeil, 2000). In the 2005 second edition of their book, Torres et al. added a section on innovative forms of reporting including photographs, cartoons, poetry and drama. Innovative formats "offer exciting options for increasing the accessibility of findings to a wide variety of audiences" (Torres, Preskill & Piontek, 2005, p. xiii). Johnson et al. recently reported on their experimental use of novel reporting formats in their STEM education evaluations. They used diagrams, drama, multiple program theories and poetry to align their practice with their values-engaged approach to education evaluation (Johnson et al., 2013).

For those wanting to experiment with novel forms of communicating evaluation results, digital technology has greatly expanded the communication repertoire. In particular, data visualization holds great promise for enhancing evaluation use through engaging more stakeholders more easily. Complex data and ideas can be grasped more quickly when presented visually. Visual presentation can also allow viewers to interact with the data. For both reasons, understanding is enhanced (Card et al., 1999; Spence 2000; Tufte 1990). A recent special issue on the use of data visualization in evaluation begins:

> *At the core of our profession is the need to communicate complex ideas to an array of stakeholders who may vary in their level of knowledge, interest, and familiarity with the evaluand and methods of measuring.* (Azzam & Evergreen, 2013, p. 3)

Azzam and Evergreen believe in the promise of data visualization to assist evaluators in their complex communication tasks. At present, data visualization is thought about mostly as providing tools for data analysis (Segel & Heer, 2010), this being the agenda of the computer scientists working in the area. Visualization techniques used not for analysis but for communication are developing quickly and are becoming pervasive in areas outside of academic social science to the extent that "communications technologies are displacing the printed page from its dominant role as the medium of scientific communication" (Boulton, 2012).

The data visualization agenda prioritizes analysis - facilitating user interaction with the data to facilitate exploration and discovery. From the evaluators' perspective, analysis is but one stage of the process. The chapters in Azzam and Evergreen's edited monograph explore the use of data visualization at all stages: understanding the program, stakeholders and context; collecting data; analysis and communicating findings. Evaluators seeking to use data visualization to enhance communication of findings will have a different set of priorities than computer scientists. For example, rather than pure interactivity, evaluators will seek a balance between telling their story and some interactivity to customize the presentation to the user's context to encourage engagement (Segel & Heer, 2010). Because visual appeal is engaging, aesthetics will be important. This dimension can sometimes be neglected by computer scientists (Lau and Moere, 2007; Moere and Purchase, 2011). Explaining the results of analysis has always involved using static visualizations, i.e. graphs. Digital media promises much more through the use of emerging techniques that Segel and Heer (2010) call narrative visualization. In this paper we present an experiment with a novel form of communicating evaluation results using narrative visualization.

In this study, patent citation analysis was used to systematically identify emerging high impact technologies in the US technology ecosystem and then to establish that Office of Science of the US Department of Energy (DOE) funds research that underpins these technology "hot spots." This big data analysis marshalled extensive data infrastructure and sophisticated analytical techniques, which required a great deal of lengthy explanation in the final report. The traditional final report was produced, but read by few to none and enjoyed by nobody. The narrative visualization in contrast, has been in use over many years by one of us (Valdez) because it is unequaled in its impact on a science policy audience. The visualization is an Adobe Flash executable file that functions as an enhanced slide show incorporating animation and sound effects to help describe the methods and convey the results. In its original form, the story is moved forward by the presenter who narrates live. The end point allows interactive drill down by the presenter and the path can be varied based on audience interest. As presented here, a narration has been recorded, and the interactive element removed due to the restrictions of the new format.

One might assume that understanding is enhanced only because over-simplified explanations of very broad issues aimed at the lowest common denominator are presented. This visualization sought to follow best practice guidelines in accurately reflecting the information contained in the data (Azzam et al., 2013, p. 9). The illustrations were carefully designed to reflect proportions and quantities in the data and results.

As is common in narrative visualization, crafting this presentation required a diverse set of skills (Segel & Heer, 2010). Expertise in data science (Breitzman), analysis (Hicks), audio recording and post-production (Arora), artistic ability (Cardona), and the vision to push beyond standard methods (Valdez) were all required to bring the project to fruition. Although the visualization was produced in 2003, the context in which to discuss it did not develop until recently. Therefore wider dissemination has been delayed until now.

At this point, the argument for the video has been made and the reader is invited to watch the video here: [URL to be provided]. To facilitate comparison between traditional reporting and narrative visualization, in the following sections we provide a traditional literature review of the techniques used and describe the method and results.

2. Literature review

In this evaluation, patent co-citation analysis was used to systematically identify emerging high impact technologies in the US and then to establish that Office of Science (DOE) funds research that underpins these technologies. Co-citation analysis of scientific papers was pioneered by Henry Small at ISI in 1973 and has been in constant development ever since (Small, 1973; Small, 2003; Klavens and Boyack, 2005). Widely used in the study and evaluation of science, co-citation also forms the basis of ISI/Thomson-Reuters identification of Research Fronts, or clusters of highly cited papers. In the 1990s the number of studies using co-citation analysis increased as computational power became more widely available. In 1999 the first patent appeared containing the term "co-citation analysis". By 2011, the term "co-citation analysis" had appeared in over 50 patents assigned to Lexis-Nexis, IBM and Xerox, among others (Halevi, 2011).

From the beginning, visualization has been used to present the results of co-citation analysis, in that the results are displayed as metaphorical maps of the scientific landscape. The "map" presents a projection into two dimensions of the position in n-dimensions of scientific areas in relation to each other. On the map are circles representing clusters of papers and lines between clusters that are strongly linked by citations in common[1]. The maps are interpreted as the location of specific fields within the realm of science as well as the "distance" between specialties (Rip, 1988.) Using VxInsight software, the metaphor has been extended into a third dimension with height representing another metric, such as number of citations to the papers in a cluster (for example see Boyack and Borner, 2003). Today, Thomson-Reuters provides research front maps at http://www.sciencewatch.com/dr/rfm/ and some of the most beautiful and sophisticated current maps are indexed in the knowledge networks section of www.visualcomplexity.com. Maps, beautiful as they can be, are not the only way to use the results of co-citation analysis. We hope to demonstrate this here by focusing attention and exploration on important individual clusters, rather than on the relationships between all clusters.

Most often patent citation analysis focuses on the cited patent and how many citations it receives (forward citations). This makes sense because research has found that highly cited patents are associated with technological and commercial success. Many studies have linked highly cited patents with other measures of success such as invention awards, increases in sales and profits, expert opinion and licensing revenues (Albert et al., 1991; Breitzman & Mogee, 2002; Carpenter et al., 1981; Hicks et al., 1986; Narin et al., 1987). Co-citation has not been applied to patents very often. Mogee and Kolar (1999) used the technique to identify the technology fronts pursued by Eli Lilly. Lai and Wu (2005) proposed using co-citation to develop a patent classification scheme. Co-citation analysis is also offered as part of the on-line patent analysis tool kit at

[1] In 2003, a selection of this type of work was published in in special section of JASIST edited by Chaomei Chen (Chen, 2003).

www.acclaimip.com. This paper hopes to encourage wider use of co-citation on patents by revealing the utility of the technique.

The funding acknowledgements on papers are another little used analytical resource. In 1997, Narin et al. included analysis of funding acknowledgements in a paper examining all US authored papers cited in US patents. Narin et al. found that NIH was the most acknowledged source of funding on biomedical papers cited in patents while NSF lead in chemistry, physics and engineering. Cronin and Shaw (1999) examined four information science journals and found that a paper's citedness was associated with journal of publication and an author's nationality, but not with funding. Harter and Hooten (1999) examined nine volumes of JASIS and found no relationship between whether an article was funded and citation count. Using grant proposals containing lists of publications and their respective funding sources, Butler examined research funded by the National Health and Medical Research Council of Australia (Butler, 2001). Exploring the accuracy with which researchers report links between publications and the grants from which they emanate, Butler found that acknowledgments data appear to accurately reflect a funding body's total research output. Boyack and Borner (2003) used data on individual grants to track paper output at the finest possible level arguing that better databases should be constructed to facilitate this type of analysis. Wang and Shapira (2011) examined the pattern of funding acknowledgments on international nanotechnology papers. They found that if funding is widely distributed across many recipient organizations, then citation counts are relatively higher. National science foundations and research councils fund relatively more international collaborations than other types of funders. In this paper we continue the work of exploring the utility of funding acknowledgements by using them to position a Federal agency's funded research within the US technology landscape.

3. Method

In this study, patent co-citation analysis was used to systematically identify emerging high impact technologies in the US technology ecosystem and then to establish that Office of Science of the US Department of Energy (DOE) funds research that underpins these technology "hot spots." (The Office of Science funds basic research, especially in the physical sciences.) The results are derived from a comprehensive analysis of the US science and technology ecosystem using bibliometric databases and techniques. The resources used in the study were these:

1. The US patent database, with assignee names cleaned up to organizations
2. The database of US publications
3. A database of papers cited in US patents with associated institutional affiliations and funding acknowledgements.
4. Co-citation clustering of patents

The advantage of co-citation analysis is currency and the ability to move beyond the patent level, to the level of technologies, without having to use pre-existing categories which can be too general to be helpful. With co-citation clustering, patents that inventors consider to be similar are identified and the analyst can deduce the technological theme being developed. The co-citation technique leverages the networked structure of the knowledge ecosystem to provide a very good way of sorting through the several million patents issued over the past several decades to identify technologies that are spurring current developments.

In this project, current developments were identified by using only references from recent patents (2001-2002, analysis conducted in 2003). In this set of references we identified all U.S. patents cited at least 10 times. The cited patents might be 1 year old or 20 years old. In this step, we eliminated 95% of the cited patents not cited 10 times by the 2001-2002 patents. We kept the top 5% patents having a high impact on emerging technology. Next we eliminated patents with long records of high citation. Out of over two million older patents, 16,000 high impact patents were left or 2% of US patents issued 1995-1999. Next we grouped together any highly cited patents that are co-cited by 2001-2002 patents into clusters and call these clusters "hot-spots."

The co-citation clustering produced 423 hot spot clusters with at least 5 patents in them. These clusters contain 10,000 or 62.5% of the high impact, emerging technology patents. The hot-spots and the next generation of patents citing them identify all points in the U.S. technological space around which a confluence of inventive activity is developing.

Hot spot patents differ from highly cited patents. Not all highly cited patents will be hot spots, and not all hot spot patents will be highly cited. For example, in 1978 Xerox was awarded a very important patent related to the development of the ethernet entitled: "Multipoint data communication system with collision detection". As of 2003, this patent had been been cited 210 times. However, only 3% of those citations were from recent patents (issued 2000-2001). This patent is no longer central to current developments. On the other hand, in 1990 American Home Products was awarded a patent entitled: "Novel benzyl-3H-1,2,3,5-oxathiadiazole 2-oxides useful as antihyperglycemic agents". This patent has been cited 16 times, which is not unusual for a patent of its age and technology class. This patent is not highly cited. But 15 of these 16 citations were from recent (2000-2001) patents, which is very unusual. This patent was in a hot-spot.

Note also, not all patented innovations and so not all hot spots are in glamorous high-tech areas like electronics, drugs, chemicals or software. A 1989 patent with the simple title “Scooter” was cited only twice in the 10 years after issue, but then things got interesting and the patent gathered 11 more citations in little more than a year. Patents citing the scooter in the early 2000s included features found in the foldable “razor” scooters.

Technological development tends to be cumulative in that innovations build on prior technology. The hot-spot methodology takes advantage of this fact. In fact, if an innovation were to emerge without any precedents, the hot spot method would miss it. A time machine built from scratch would be an exciting technological development but would not be seen in a hot spot analysis.

Despite this potential problem, which would bedevil any citation analysis, hot-spot analysis is a powerful tool to map out current areas of innovation activity. The tool allows us to get beyond the patent level to look at technology areas, yet it permits us to do this without having to fly up to 30,000 feet and talk in generalities such as organic chemicals or semiconductors. Using the hot-spot approach, we identify specific technologies in which innovation is concentrated. It enables us to see technologies of current interest hidden among the three million or so U.S. patents issued since 1975. See [ref blinded] for a more detailed methodological explanation including validation exercises.

4. Results

In part the results of the project are the demonstration that the analysis can be presented in video format. In this section we briefly repeat in text the analytical results described in the video.

The analysis identified 16,000 US hot spot patents, or patents whose impact on recently issued patents is particularly strong. Co-citation clustering organized 10,000 of these patents into 423 clusters containing five or more patents. The DOE presence among these patents is stronger than expected. For patent issue years 1995-1999, 2% of all US patents are in hot spots but 4.5**%** of DOE patents are in hot spots. Thus DOE-linked patents are found in hot spots more than twice as often as expected. In addition, DOE research underpins more than five times the expected number of hot spots, given the size of their research funding. DOE accounted for 1.6% of US civil R&D in 2000, and we detected DOE contributions in 9**%** of hot spots (37 of 423).[2]

With the hot spot structure in place, we can identify clusters supported by DOE research. A hot spot cluster is said to benefit from DOE research if there is more than one DOE-linked patent in it and DOE-linked patents are at least 10% of the hot spot – a 10%/1+ patent rule. A DOE linked patent is one that arose from

[2] Patents resulting from DOE research or patents citing DOE research accounted for 1.2% of US patents in 2000

DOE research or that cites DOE research papers as prior art. DOE supported research is well represented in the science that underpinned hot spots in US innovation in 2001-2002, having an especially strong impact in biotechnology, advanced materials and electronics.

DOE's impact ranges broadly across the technology landscape. Table 1 lists technology areas and the share of clusters that are DOE-linked. Because the hot spot technique identifies technologies at a very detailed level, we can drill down to precisely identify technologies to which DOE is contributing. Table 2 lists DOE-linked hot spot clusters. Technology areas in which DOE has a big impact are: biotechnology; assays in arrays, biochips, microfluidics; microelectronic fabrication technology; microelectromechanical technology; energy storage/fuel cells, battery; polymers synthesis and polymer fabrication technologies and medical devices – in particular medical imaging.

Table 1 - Number of DOE and non-DOE clusters in each broad technology area

Broad area	DOE	Other	DOE %
Advanced Material/Chemicals	9	49	16%
Biotechnology	14	5	74%
Electronics/Computer Hardware/Communications	9	122	7%
Information Technology	1	53	2%
Manufacturing	2	47	4%
Medical	3	77	4%
Other		32	

Table 2 – List of DOE linked hot spot clusters

Advanced Material/Chemicals
- Batteries With Polycarbon Sulfide
- Fuel Cells
- Metal-Air Battery
- Microsensor Mass & Chemical
- Molybdenum & Iron Catalyst Production Of Syndiotactic 1,2 Polybutadiene
- Nanocrystals/Quantum Dots Flourescence Probes
- Olefin Polymerization & Related Catalysts
- Olefin Polymers

Biotechnology
- Affymax/metrix Biological Chip
- Caliper Lab On Chip
- Combinatorial Chemistry
- Remotely Programmable Matrices With Memories
- DNA Amplification & Detection Including Rolling Circle Amplification
- DNA Shuffling And Recombination Directed Evolution
- Fiber Optic Biosensor Array
- Gene Chip Manufacturing esp. Binding & Detection
- Mass Spectrometry & DNA
- Microfluidic Devices
- Nucleic Acid Chips
- Nucleic Acid Detection Using Electric Currents
- Plant Genetic Engineering - Monsanto Co-citing
- Sorting & identifying polynucl. using oligonuc. tags

Medical
- Hyperpolarized Noble Gases For Medical Imaging
- Imaging Tissue with Autofluorescence
- Inactivating Viral And Bacterial Blood Contaminant

Electronics/Computer Hardware/Communications
- Extreme UV Lithography
- IBM Magnetic Tunnel Junction Device
- Method Of Semiconductor Fabrication – Hynix
- Microelectromechanical Devices esp. Actuators
- Microelectromechanical Fluid Ejection
- OLED's Including Thin Flexible Encapsulation
- Semiconductor Fabrication Alkaline Earth Oxide
- Semiconductors/ Metal Thin Films In Capacitors Largely Micron Co-citing
- Short Range Radar Object Locator

Information Technology
- Digital Security - Steganography, Watermarking

Manufacturing
- Liquid Carbon Dioxide Dry Cleaning
- Stirling Engines, Heat Engine

5. The importance of the broader audience

"The mission of the Energy Department is to ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions" (US Department of Energy). One way of estimating the success of DOE's research is to measure the extent to which the DOE funds transformative science and technology using techniques such as hot-spot identification and analysis. However, it can also be argued that the success of DOE – or any agency in the US for that matter – is a function of its ability to lucidly communicate its accomplishments to the public and decision makers. This is challenging because DOE's research portfolio touches on many complex technical developments, because the analysis relies on techniques understood by a small specialist community, and because stakeholders cannot be compelled to devote the hour required to read the report. Here, we show that new forms of media can be used to report the results of complex indicator based analyses. Our video "report" included the traditional explanatory elements of background, context, methodological explanation and results. Yet compared to traditional text reports, the form has the potential to enhance the dissemination and reporting of science and technology evaluation for greater impact on policy discourse.

Our argument in favor of narrative visualization needs to be balanced with consideration of the limits of the form that surfaced during informal and formal presentations of this project. Evaluation results need to be communicated to multiple audiences - internal and external - for a variety of purposes – budgeting, program management, public affairs etc. Different forms of communication suit different audiences. Therefore best practice is to deploy multiple formats (Lawrenz et al. 2007; Johnson et al. 2013) as thought out in advance in an evaluation reporting plan (Torres et al. 2005). Torres et al advocate devising effective communication plans using their structured, 50 point analysis of every stakeholder. This type of analysis will help evaluators decide for whom and when a narrative visualization might fit into their broader portfolio of reporting options. Unfortunately, the necessity of using multiple forms of communication works against the viability of visualization in a resource constrained environment. Visualizations, attractive though they are, will not suit the needs of every stakeholder, but because visualizations are relatively expensive, their production might exhaust resources, leaving nothing for other communication formats. This was a problem here.

Another difficulty with this format is its standalone nature. The tables and figures in traditional reports can be reworked or copied into new documents. The ability of stakeholders to transform evaluation results and combine them with other information to produce new documents and presentations enhances the usefulness of results to sponsors. That flexibility is sacrificed with this presentation format.

A final problem perversely arises from the very effectiveness of narrative visualization in enabling broader communication of complex analyses. If an analysis goes no further than frequencies, trends and correlations, traditional tables and graphs will be used because they are adequate to the job. Assume then that complex and innovative analyses is conveyed with visualization. The direct sponsor, most closely engaged in the project, will understand the motivation and rationale for the work, the data and the main lines of analysis. With this close involvement, the sponsor understands and benefits from a report as well as a narrative visualization. The sponsor will be able to reach more people with the narrative visualization, who will engage with the results in consequence. The strength of the technique will be its ability to engage and persuade non-technical stakeholders. In this visualization may be able to make a unique contribution to the communication of evaluation results.

However, in research evaluation, scientists are also stakeholders and they too are more likely to engage with a narrative visualization than with a report. Scientists will not necessarily be persuaded by the visualization. First, academics in general mistrust visual presentation. Second, scientists may not understand or trust the techniques. Perhaps this is because they were not taught them in college or because as scientists they mistrust social science in general. Whatever the reason, their learning the results of the study will not be the same thing as them believing the results of the study. Therefore, in research evaluation, wider dissemination to scientists may ironically lead to wider dismissal of the value of the work.

Against these limitations are set the unique strengths of visual presentation. Accessible presentation of evaluation may increase impact. Policymakers are limited in their capacity to absorb and process large amounts of information, and rely on prepackaged solutions when encountering routine choice situations (Jones, 2003). In this context, innovative presentations that compact and smooth the delivery of complex information with the goal of making policy research more easily accessible and comprehensible, might enhance the influence of high quality information on decision making, thus advancing the goals of democratic participation. Such a development would be welcome especially in science and technology policy, where specialist techniques such as bibliometrics, patent analysis and data mining are used (Coates et al., 2001).

In our concern not just with sound analysis but also with communicative form, we marry two goals of real-time technology assessment (RTTA), which are: 1) to facilitate understanding about a technology's development through text-mining, bibliometrics, interviews, etc., and 2) to promote communication between researchers and the public to identify expectations and consequences of socio-technical interaction (Guston and Sarewitz, 2002). Here we seek to unite the findings of a complex research program with the need to connect active and latent actors in the policy network in previously untapped ways. While our work is only a small contribution to this larger goal, we hope that it acts as an exemplar for future work.

The value of visualization is perhaps most striking in the classroom. Students' enthusiastic response to the material offered an unexpected moment to reflect on the progress of interdisciplinary social science in educational settings in this new era of rapid evolution in information and communication technologies. Indeed, previous research in the use of technology for educational purposes has shown that the strategic separation of graphics and text into narrative formats increases student understanding and retention (Wiebe and Annetta, 2008). Weibe and Anetta (2008) confirm that when narratives are present, students focus more on the substantive content of graphics. The idea that this approach can aid classroom learning comes with at least two caveats. Firstly, the design of such multimedia tools should consider "complex learning" that combines technology with traditional lecture and discussion and possible unconventional forms of evaluation (Mandl cited in Backer, 2004). Secondly, students differ in learning styles, some of which are more or less receptive to multimedia forms of teaching (Choi et al., 2008).

As the academic community prepares to educate the next generation of technologically sophisticated students, we must ask whether our collective research presentation methods are as inspiring and relevant as possible. In many cases, the answer is no (Felder and Silverman cited in Choi et al., 2008). It is our opinion that this research – and more importantly, the novel presentation format – is one step in the right direction to attract new interest in "fun" ways to present and eventually conduct state-of-the-art empirical evaluation. In a world where normative claims increasingly supersede substantive evidence, higher-education tools that overcome complexity without sacrificing theoretical and methodological integrity should be of considerable interest to scholars across a variety of disciplines.

6. Conclusions

Science is a cumulative enterprise - that is today's discoveries build upon past work and today's research will form the foundations for future innovation. Also, knowledge is structured in a network - that is a discovery will draw upon a wide range of past efforts, some very similar to itself and others quite different. And today's discovery will contribute to a broad range of future efforts, some closely related and others quite distant. Because knowledge is cumulative and networked in its structure, the contributions to knowledge made by a large enterprise such as the Department of Energy are not easy to describe. One has to look back in time, as well as realize that impacts will develop over time, into the future. Also, tracing all impact entails ranging far and wide over the knowledge landscape. In addition, the audience is often less interested in the impact on knowledge, than in outcomes, or the contribution to the economy through generation of innovative new technologies of relevance to US firms. The work presented here was designed to address the problem of making visible the outcomes of the research sponsored by the Office of Science at the Department of Energy. We do this in a way that pays respect to the cumulative, networked character of knowledge.

We present here a co-citation analysis of the US patent system, with linkages to papers cited in the patents which are in turn linked to funding agencies through funding acknowledgments on the papers. Co-citation analysis has been widely used on papers, but little used on patents. Funding acknowledgements have been not been widely used in analysis. Others use visualization techniques to produce maps of the scientific landscape based on co-citation results. We produce no maps. Rather our visualization seeks to tell the story a different way.

This text accompanies the video: *Technology hot spots and the Office of Science*. As the video shows, this analysis generated a high level overview of the US technological landscape in 2001-2002 and identified "hot" emerging technologies within that landscape. We were able to trace back to reveal where Office of Science research support underpinned the emerging technologies. The Office of Science was shown to have broad impact across a range of technology areas. U.S. firms citing Office of Science research were identified. In doing this we also found that the Office of Science has 2.8 times the expected number of hot spot patents. The analysis suggests a high return to the tax dollars spent on Office of Science research.

The hot spot technique is a powerful one for tracing research outcomes. It takes advantage of the cumulative nature of technological advance by using references made from current patents to past, predecessor inventions. Because it works with system level, big data resources it is able to track impacts across the innovation ecosystem. With the hot spot technique, the complex networks that characterize technological advance are not a barrier to understanding, but a resource. The technique follows the myriad connections in the networked structure that characterizes the advance of knowledge to reveal the broad impacts of research funding.

Mindful of the need to describe complex analyses to non-specialist audiences, we used narrative visualization to convey the results of this analysis. The strengths of narrative visualization as compared to traditional reporting are that techniques and results can be conveyed more effectively and quickly than is possible using text. This is important if the large amounts of money spent on this kind of work are going to provide value to more than a narrow specialist audience. In policy work in particular, being able to reach a broad and non-specialist audience is crucial to informing decision making. The challenges in using these techniques include the cost required to bring onto the team additional skills, the difficulty analysts have in articulating their work in a visual form, and the cool reception such a presentation will likely receive at present in traditional academic circles. Over the longer term, if it can be shown that the understanding achieved through the visualization is comparable to that achieved by reading a long technical report, skepticism may decrease. We advocate augmenting traditional presentation modes to succeed in a world of increasing audience diversity, information clutter and extreme competition for the attention of stakeholders.

7. References

Albert, Michael, Daniel Avery, Paul McAllister & Narin, F. (1991) 'Direct validation of citation counts as indicators of industrially important patents', *Research Policy*, 20: 251–259.

Azzam, Tarek, and Stephanie Evergreen, eds. (2013) 'Data Visualization: Part 1', *New Directions for Evaluation*, Number 139. John Wiley & Sons.

Azzam, Tarek, Evergreen, S., Germuth, A.A. & Kistler, S.J. (2013) 'Data Visualization and Evaluation', *New Directions for Evaluation*, 139: 7-32.

Backer, Patricia (2004) ‘Using multimedia to teach a class on technology and society’, *The Journal of Technology Studies*, 30/2: 77-79.

Boulton, Geoffry (2012) ‘Open your minds and share your results’, *Nature*, 486: 441.

Boyack, Kevin W. and Katy Börner (2003) ‘Indicator-assisted evaluation and funding of research: Visualizing the influence of grants on the number and citation counts of research papers’, *Journal of the American Society for Information Science and Technology*, 54/5: 447–461.

Breitzman, Anthony & Mogee, M.E. (2002) ‘The many applications of patent analysis’. *Journal of Information Science*, 28/3: 187–205.

Butler, Linda (2001) ‘Revisiting bibliometric issues using new empirical data’, *Research Evaluation*, 10/1: 59-65.

Card, Stuart, Jock Mackinlay & Shneiderman, B. (1999) *Readings in Information Visualization, Using Visualization to Think.* Burlington, MA: Morgan Kaufmann.

Carpenter, Mark, Francis Narin & Woolf, P. (1981) ‘Citation rates to technologically important patents’. *World Patent Information*, 4: 160–163.

Chang, Connie K.N. and Anthony Breitzman (2009) ‘Using patents prospectively to identify emerging, high-impact technological clusters’, *Research Evaluation*, 18/5: 357-364.

Chen, Chaomei (2003) ‘Visualizing Scientific Paradigms: An Introduction’, *Journal of the American Society for Information Science and Technology*, 54/5: 392-393.

Choi, I., S.J. Lee, & J.W. Jung. (2008) ‘Designing Multimedia Case-Based Instruction Accommodating Students’ Diverse Learning Styles’. *Journal of Educational Multimedia and Hypermedia*, *17/*1: 5-25.

Coates, V., M. Farooque, R. Klavans, K. Lapid, H. A. Linstone, C. Pistorius, & A.L. Porter (2001) ‘On the Future of Technological Forecasting’, *Technological Forecasting and Social Change*, 67/1: 1-17. doi:10.1016/S0040-1625(00)00122-0

Cronin, B., & Shaw, D. (1999) ‘Citation, funding acknowledgement and author nationality relationships in four information science journals’, *Journal of Documentation*, 55/4: 402–408.

Guston, D. H., & D. Sarewitz (2002) ‘Real-time technology assessment’, *Technology in Society*, *24/*1-2: 93-109. doi:10.1016/S0160-791X(01)00047-1

Halevi, Gali (2011) ‘The Beginning of a Beautiful Friendship – Social Sciences Research and Industry Products’, *Research Trends*, November. Accessed on July 13, 2012 at: http://www.researchtrends.com/issue25-november-2011/the-beginning-of-a-beautiful-friendship-%E2%80%93-social-sciences-research-and-industry-products/ .

Harter, S. P., & Hooten, P. A. (1992) ‘Information science and scientists: JASIS, 1972–1990’, *Journal of the American Society for Information Science*, 43/9: 583–593.

Hicks, D.M., B.R. Martin and J. Irvine, "Bibliometric Techniques for Monitoring Performance in Technologically Oriented Research: the Case of Integrated Optics", R&D Management, 16: 211-224, 1986.

Johnson, Jeremiah, et al. (2013) ‘Exploring Alternative Approaches for Presenting Evaluation Results’, *American Journal of Evaluation* 34/4: 486-503.

Jones, B. D. (2003) ‘Bounded Rationality and Political Science: Lessons from Public Administration and Public Policy’, *Journal of Public Administration Research and Theory*, *13/*4: 395-412. doi:10.1093/jpart/mug028

Klavans, Richard, Boyack, Kevin W. (2005) ‘Identifying a better measure of relatedness for mapping science’, *JASIST* 57:251-263.

Lai, Kuei-Kuei and Shiao-Jun Wu (2005) ‘Using the patent co-citation approach to establish a new patent classification system’, *Information Processing & Management*, 41/2: 313-330.

Lau, Andrea, and Andrew Vande Moere (2007) ‘Towards a model of information aesthetics in information visualization’, *Information Visualization* IV'07, 11th International Conference, IEEE.

Lawrenz, Frances, Arlen Gullickson, and Stacie Toal (2007) ‘Dissemination handmaiden to evaluation use’, *American Journal of Evaluation*, 28/3: 275-289.

MacNeil, Cheryl (2000) ‘The prose and cons of poetic representation in evaluation reporting’, *American Journal of Evaluation*, 21/3: 359-367.

Moere, Andrew Vande, and Helen Purchase (2011) ‘On the role of design in information visualization’, *Information Visualization*, 10/4: 356-371.

Mogee, Mary Ellen and Richard G Kolar (1999) ‘Patent co-citation analysis of Eli Lilly & Co. patents’, *Expert Opinion on Therapeutic Patents* 9/3: 291-305.

Morgan, M. G., & Pea, J. M. (2003) Analysis, governance, and the need for better institutional arrangements. In M. G. Morgan & J. M. Pea (eds.), *Science and Technology Advice for Congress,* pp. 3–18. Washington, D.C.: Resources for the Future.

Narin F, Hamilton KS, Olivastro D. (1997) ‘The increasing linkage between US technology and public science’, *Research Policy*, 26: 317-330.

Narin, Francis, Elliott Noma & Perry, Ross (1987) ‘Patents as indicators of corporate technological strength’, *Research Policy,* 16: 143–155.

Neal, H. A., Smith, T., & McCormick, J. (2008) *Beyond Sputnik: U.S. Science Policy in the 21st Century*. Ann Arbor, MI: University of Michigan Press.

Piereson, James and Naomi Schaefer Riley (2013) ‘The problem with public policy schools’, *Washington Post* opinion, December 6.

Rip, A. (1988) ‘Mapping of science: possibilities and limitations’. In Van Raan A.F.J. (ed.) *Handbook of Quantitative Studies of Science and Technology. pp*. 253-273. North-Holland: Elsevier.

Segel, Edward & Heer, Jeffery (2010) ‘Narrative Visualization: Telling Stories with Data’, *IEEE Transactions on Visualization and Computer Graphics*, November, 1139-1148.

Shulha, Lyn M., and J. Bradley Cousins (1997) ‘Evaluation use: theory, research, and practice since 1986,’ *American Journal of Evaluation*, 18/3: 195-208.

Small, Henry (1973) ‘Co-citation in the scientific literature: A new measure of the relationship between two documents’, *Journal of the American Society for Information Science*, 24/4: 265–269.

Small, Henry (2003) ‘Paradigms, citations, and maps of science: A personal history’, *Journal of the American Society for Information Science and Technology*, 54/5: 394–399.

Smith, K. & Larimer, K. (2009) *The Public Policy Theory Primer*. Boulder CO: Westview Press.

Spence, Robert (2000) *Information Visualization.* New York City: ACM Press.

Teirlinck, Peter, et al. (2013) ‘Closing the policy cycle: Increasing the utilization of evaluation findings in research, technological development and innovation policy design’, *Science and Public Policy* 40/3: 366-377.

Torres, Rosalie T., Hallie Preskill, and Mary E. Piontek. (2005) *Evaluation strategies for communicating and reporting: enhancing learning in organizations*, 2nd edition. Thousand Oaks, CA: Sage.

Tufte, Edward (1990) *Envisioning Information*. Cheshire CT: Graphics Press.

US Department of Energy. Retrieved from energy.gov on July 18, 2012.

Wang, Jue and Philip Shapira (2011) ‘Funding acknowledgement analysis: an enhanced tool to investigate research sponsorship impacts: the case of nanotechnology’, *Scientometrics*, 87/3: 563-586.

Weiss, Carol H. (1998) ‘Have we learned anything new about the use of evaluation?’ *American Journal of Evaluation* 19/1: 21-33.

Wiebe, E. & L. Annetta (2008) ‘Influences on Visual Attentional Distribution in Multimedia Instruction’, *Journal of Educational Multimedia and Hypermedia*, 17/2: 259-277.