# **The Global Impact of Science Gateways, Virtual Research Environments and Virtual Laboratories**

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## **Abstract**

Science gateways, virtual laboratories and virtual research environments are all terms used to refer to community-developed digital environments that are designed to meet a set of needs for a research community. Specifically, they refer to integrated access to research community resources including software, data, collaboration tools, workflows, instrumentation and high-performance computing, usually via Web and mobile applications. Science gateways, virtual laboratories and virtual research environments are enabling significant contributions to many research domains, facilitating more efficient, open, reproducible research in bold new ways. This paper explores the global effect of these programs in increasing research impact, demonstrates their value in the broader digital landscape and discusses future opportunities.

## 1. Introduction

Science gateways, virtual laboratories and virtual research environments (hereafter science gateways) refer to various kinds of community-developed digital interfaces to advanced technologies that support research. They are used in a wide variety of scientific domains, from high energy physics, astrophysics to humanities and the social sciences. By tailoring digital environments to community needs, science gateways perform a key role in integrating elements of the e-infrastructure landscape, providing online access to software, data, collaboration tools, instrumentation and high-performance computing, to facilitate increased research impacts.

Science gateways are enabling significant contributions in many research domains, with national and international initiatives to develop gateways further demonstrating their importance and value. This paper explores the global impact of these programs, highlighting their successes, values in the broader landscape and future focus. The paper begins with a discussion on the definition of terms, then highlights the role and value of science gateways in the digital research environment. This investigation then documents national and international programs in this field, and examines the impact of science gateways, to evidence how science gateways facilitate more efficient, open, reproducible research in bold new ways.

## 2. Definition of terms

A number of terms are often used in this field, including science gateways, virtual laboratories and virtual research environments (VREs). Different terms exist in large part for historical reasons; science gateways evolved in the USA, virtual laboratories in Australia, and VREs in Europe.

Shahand’s analysis of science gateways research defines science gateways as “web-based enterprise information systems that provide scientists with customized and easy access to community-specific data collections, computational tools and collaborative services on e-Infrastructures.” [1]. This definition is similar to that used by the Science Gateways Community Institute, the USA’s National Science Foundation-funded coordination project in this area, which also differentiates between science gateways and the generic cyberinfrastructure on which they build [2]. Australia’s virtual laboratory community uses similar definitions, with an emphasis on access to integrated data, computational environments and tools [3].

Between 2004-2011, Jisc funded the development of a number of VREs in the UK, and defined VREs more broadly than science gateways and virtual laboratories: “The term VRE is now best thought of as shorthand for the tools and technologies needed by researchers to do their research, interact with other researchers ... and to make use of resources and technical infrastructures available both locally and nationally” [4]. Horizon 2020, the European Commission’s research and innovation framework programme, suggests that VREs “should integrate resources across all layers of the e-infrastructure (networking, computing, data, software, user interfaces), should foster cross-disciplinary data interoperability and should provide functions allowing data citation and promoting data sharing and trust.” [5]

Carusi and Reimer ‘s work notes the relevance of alternative terms including collaborative e-research community, collaboratory and virtual research community [6], and identifies convergence on a set of characteristic features: “an electronic web-based environment for a) access to data, tools, resources; b) co-operation or collaboration with other researchers ...; c) cooperation at the intra- and inter-institutional levels; or d) preserving or taking care of data and other outputs.” Candela, Castelli and Pagano’s analysis of VREs also identifies five distinguishing features that are similar, but more focussed on serving the needs of a community of practice” [7]. Shahand also suggests that science gateways usually have five functional properties: usability, scalability, integration, automation and sharing and reuse [1].

It should be noted that science gateways can vary in scope depending on the problems they aim to address and the domains they support. In this paper, an inclusive definition of science gateways is used, covering all the aspects raised above.

## 3. The value of science gateways in the e-infrastructures landscape

Science gateways are a key component of the future digital research environment, enabling researchers to utilize a global network of interacting digital platforms to access and share the leading-edge data and tools that are critical for their research. They both facilitate, and are supported by, broader movements such as open research, open science, open source software and open data. Consequently, science gateways are valuable to a range of stakeholders: individual researchers, research communities, research organizations and institutions, industry, government and funding agencies.

Defining science gateways in terms of common characteristics and functionality assists in identifying their value to their stakeholders. Science gateways lower barriers by hiding the complexity of the underlying digital research infrastructure and simplifying access to best-practice tools, data and resources, thereby democratizing their usage. They can enable collaboration and build communities, sharing data and analyses among multidisciplinary and geographically dispersed research groups, leading to increased openness. They can enable research to be undertaken more efficiently through the provision of modelling and other software and hardware resources through a single portal, and enable research to be undertaken that would not otherwise be conducted. Researchers no longer need to be physically co-located because resources can be globally distributed, and this also enables inclusion of less advantaged researchers/institutions. By sharing resources across multiple institutions, the costs of setting up and supporting research infrastructure is lowered, as each institution is no longer required to support a replica of data, compute and tools at their site. For gateways that are open source, their very building and evolution can be democratized.

Science gateways provide these benefits to users by performing a key role in integrating e-infrastructure layers, in particular by linking together elements that can include data storage, tools, authentication, networks, cloud and high-performance computing, and access to data resources for reuse (sometimes called ‘data as infrastructure’). This integration tailors digital environments to community needs without the need for expertise in navigating the enabling information technology infrastructure that supports their work. They simplify linkage to other infrastructures, such as synchrotrons, ground based telescopes, satellites, DNA sequencers, distributed archives and performance art studios. Science gateways may also provide other tools; in some cases, a science gateway architecture supports the whole research process from hypothesis generation to results analysis, including provenance information, contributing to reproducible science. Science gateways also have a role in education, training researchers of the future and providing access to methods formerly accessible only by experts.

Science gateways interact with the e-infrastructures landscape in multiple ways. At the broadest level, science gateways play a key role in driving standards and policy compliance, supporting initiatives including open research, open science, open source software, and open data. Science gateways can both drive standards and act as testbeds, as the increased user expectations encouraged by science gateways can drive requirements for harmonization. These standards often arise from sharing of best practice, with communities of practice addressing issues including reproducibility, sustainability, interfaces to cloud computing, workflows, integration of scientific instruments, success metrics, usability studies, scaling, mobile applications and security. An increasing number of international organizations address some of these issues, including the Software Sustainability Institute, Workshop on Sustainable Software for Science: Practice and Experiences (WSSSPE), the FORCE11 Software Citation Working Group and the Centre for Open Science. With diverse and constantly changing technologies available, collaboration among practitioners continues to be essential to share best practice.

Science gateways also provide valuable resources for cross-disciplinary research, and increased interoperability across science gateways will enable more multidisciplinary research. The adoption of common interfaces and formats to build a global network of science gateways will further promote open and reproducible science, and will increase the availability and usage of existing scientific tools and data. This will lead to the emergence of a new class of scientific services such as application stores, search engines and continuous integration services. Science gateways are beginning to access the services of other gateways, allowing gateway developers to design interfaces and implement functionalities specific to their communities, yet use already built infrastructure as it exists elsewhere.

Whilst some gateways already cross a number of disciplines to answer research questions, a global, decentralized network of science gateways may emerge. In this network, platforms would expose a consistent front through open specifications offering common interfaces, formats and protocols, allowing for the exchange of data, processing tools and experiments. In such a network, common web APIs such as Agave [8] or CARMIN [9] will expose methods to query and manipulate data, to run data processing tools and to share experiments. Description formats such as the Common Workflow Language [10] and Boutiques [11], which leverage the now-mature virtual containerization systems, will represent and install processing tools consistently in multiple science gateways from a single description. At the data level, domain-specific description formats such as the Neuroimaging Data Model [12], the Brain Imaging Data Structure [13] or the activities and data models provided by the International Virtual Observatory Alliance (IVOA) [14], will facilitate the exchange of datasets and the improvement of existing data models for new categories of scientific experiments.

The majority of analyses of both specific science gateways and large e-infrastructure programs emphasize the importance of appropriate skills and training, and many of the organizations mentioned here include a focus on this crucial need. A key question is what skills do all researchers need, versus what will remain as specialist knowledge, particularly with regard to informatics. Where specialist skills are needed, career paths, recognition mechanisms and training opportunities are critical, as common issues emerge in integrating tools, applications and data collections through a tailored web-based environment. In it also essential that scientists, researchers and students are able to learn and adopt a new set of software-related skills and methodologies, as well as learning to collaborate virtually amongst teams that are widely distributed.

## 4. Science Gateways Programs

Whilst science gateways have historically been enabled through a wide variety of mechanisms, they are now increasingly facilitated through national and international programs that specifically facilitate their development and sustainability. International initiatives focused on science gateways have also evolved through the work of global consortiums, journals and conferences.

National and international programs focusing on the development of science gateways include:

● CANARIE, a non-profit corporation, with the major investment in its programs and activities provided by the Government of Canada, funds the development of research software that enables Canadian researchers to more quickly and easily access research data, tools and collaborators. Since 2007, CANARIE has provided funding for 37 science gateway projects [15].

* Science Gateways Community Institute, funded in 2016 for USD$15 million over five years by USA’s National Science Foundation, to act as a focal point to facilitate the development of a sustainable software ecosystem for science gateways [16]. It is one of the two initial Scientific Software Innovation Institutes funded under the Software Infrastructure for Sustained Innovation (SI2) program [17]. SI2 funds software projects of varying scales, from small group research software to the large software institutes, including specific science gateways themselves as well as project developing general software that can be used to build gateways.
* European Union funding mechanisms include the Seventh Programme Framework (FP7) and Horizon 2020. FP7 supported VRE projects from 2007-2013. For example, SCI-BUS explored new possibilities for European user communities to create custom science gateways through a generic-purpose gateway technology [18], and the Catania Science Gateway Framework provided application developers with tools to develop science gateways [19]. Since 2014, Horizon 2020 has supported a number of European VRE projects including BlueBridge, EVER-EST, VRE4EIC, WEST-Life, VI-SEEM and MUG [20]. Most VREs are domain specific, however, there are also now initiatives creating toolsets for the creation of science gateways; VRE4EIC, will provide a Europe-wide interoperable VRE to empower multidisciplinary research communities [21]. Other Horizon 2020 projects include Sci-GalA (Energizing Scientific Endeavour through Science Gateways and meta-Infrastructures in Africa), which promotes the uptake of science gateways in Africa [22].
* National eResearch Collaborative Tools and Resources (Nectar), funded by the Australian Government, has distributed over AUD$20 million since 2011 specifically to facilitate software infrastructure programs that included the development of twelve virtual laboratories. These virtual laboratories have received an additional AUD$20 million in co-investment [3].

Development of science gateways is increasingly complex, and communities of practice have formed across international initiatives through global consortia, journals and conferences. The very impetus for this paper comes from the International Coalition on Science Gateways, an international forum that brings together national initiatives to provide leadership on future directions for science gateways, facilitate awareness and identify and share best practice in the field [23]. The Virtual Research Environment Interest Group within the Research Data Alliance brings together initiatives actively developing VREs, representatives of common infrastructure services and researchers, to identify the necessary technical aspects, governance issues and best practice required to support a more coordinated approach [24].

Workshops focusing on science gateways have been highly successful for over ten years in USA and eight years in Europe [25], and the International Workshop on Science Gateways - Australia is being held for the third year in Australia [26]. Initiated through the annual workshops, associated special issues on science gateways have been published by journals including Concurrency and Computation [27, 28] and Journal of Grid Computing [29]. A number of conferences also now include science gateways streams, including the Hawaii International Conference on System Sciences [30]. Conferences such as the XSEDE series, now the Practice and Experience in Advanced Research Computing (PEARC), also encourage submissions on gateway-related topics. The IEEE Technical Committee on Scalable Computing also includes a Technical Area on Science Gateways that aims at improving the state of research and education in scalable computing [31].

## 5. The impact of science gateways

A range of ways exist to quantitatively provide evidence for the impact of individual science gateways. Traditional metrics such as user numbers are still actively used and some groups used more impact-focussed studies to demonstrate contingent valuation. These are often used alongside emerging measures such as software citation [32]. However, different science gateways (programs) utilize different combinations of measures. It would also be useful to be able to analyse the sustainability of science gateways (beyond initial grant funding) as another measure of success.

It is difficult to make comparisons across science gateway programs due to their different structures and ways of measuring impact. For example, Australian virtual laboratories funded under Nectar recorded over 19,000 users in 2017 across 12 virtual laboratories, including, on average, users from over 20 international organizations and 30 Australian organizations. In contrast, CANARIE defines users as referring to research teams or groups, rather than individual researchers. Another measure of impact includes e-infrastructure usage statistics, for example, the number jobs on the US-based XSEDE program. While XSEDE does not fund gateways, dozens of gateways use its computing resources and in fact in the fourth quarter of 2016, 77% of XSEDE users did their computing via science gateways. Nevertheless, there are many successful gateways that do not need high-end computing, for example, the vast majority of the hundreds of thousands of nanoHUB users [33], for which such metrics would not be appropriate.

Part of the evidence for the value of science gateways comes from work expanding recognition of the importance of e-infrastructures, such as Mayernik, Hart, Maull and Weber’s work [34]. They note the increasing recognition that “traditional assessments of research impact have missed broad swaths of important activities, including the benefits associated with the collection, management and preservation of digital resources, such as data and software”. Metrics for quantitatively measuring the impacts of analytical tools over data are now beginning to emerge, and can contribute to the valuation of science gateways. Beagrie and Houghton’s work on the European Bioinformatics Institute (EMBL-EBI) assessed the value and impact of the EMBL-EBI by identifying four valuation levels: access (use) value, contingent valuation, efficiency savings and return on investment [35]. This was applied to a range of EMBL-EBI services, including both data access and analytical services over the data – one of very few studies examining the latter.

The need for science gateways is also being demonstrated through increasing acknowledgment of the critical role of software in research. A 2009 survey by Hannay, MacLeod, Singer, Langtangen, Pfahl and Wilson with 2,000 responses showed that 84 percent of researchers view the development as software as "important or very important for their own research" [36]. The USA’s National Science Foundation’s research software vision identifies software as “directly responsible for increased scientific productivity and significant enhancement of researchers' capabilities” [17]. Further, a 2014 National Science Foundation-funded survey with 5,000 respondents indicated that 88% relied on science gateway-like interfaces to conduct their work and 57% were themselves involved in some capacity in the creation of these [37].

A recent study applied a similar methodology to the Industrial Ecology Virtual Laboratory [38]. Wiedmann’s analysis of 30 IELab application publications concluded that two-thirds of the studies would not have been possible without the Industrial Ecology Virtual Laboratory, and a further 16% would have required considerable extra resources to complete. This type of contingent valuation could also be inferred from other metrics, such as the emerging emphasis on software citations, an area where organisations such as the FORCE11 Software Citation Working Group [39] have undertaken significant work. For example, the CIPRES Science Gateway has enabled 3,000 publications since 2010. Without this science gateway, many users would not have undertaken this type of research, instead needing to set up their own clusters, and install, maintain and optimize the many pieces of software offered via CIPRES [40].

## 6. Conclusion: opportunities for science gateways

Science gateways have been a valuable addition to the digital infrastructure landscape, facilitating more efficient, open, reproducible research. The many science gateway initiatives available provide abundant opportunities for reflection, identification of best practice and analysis of beneficial ways forward. Some of the key areas in which continued collaboration may advance the field include:

● Technical solutions for the development of science gateways, including interoperability, standards, software registries, and data management

● Best practices and policies for the valuation of science gateways, including incentives for open science, reproducibility, data and software citation

● Sustainability models for the development and exploitation of science gateways, including development of skills, training, career paths and funding.

The ongoing investment in national and international programs, in tandem with community and disciplinary initiatives, are facilitating the development of many communities of practice to address these issues, including ways to demonstrate the value of contributions of individuals, science gateways, and national and international programs to this field. Increasing coordination across these varied initiatives will continue to improve identification of best practice and development of policies and standards, enhancing the ability of science gateways to increase impact of research.

## References

[1] Shahand, S. Science gateways for biomedical big data analysis [dissertation].

Amsterdam: University of Amsterdam; 2015.178p. <http://hdl.handle.net/11245/1.490613>.

[2] SGCI. What is a Science Gateway. 2017 [cited 2017 Feb 20]. <http://sciencegateways.org/about/science-gateway-basics/>.

[3][Nectar.](http://webarchive.nationalarchives.gov.uk/20140702233839/http:/www.jisc.ac.uk/whatwedo/programmes/vre.aspx) Nectar Impact. 2016 [cited 2017 Feb 20]. <https://nectar.org.au/nectar-impact/>.

[4] [Jisc. Virtual research environment programme. 2013](http://webarchive.nationalarchives.gov.uk/20140702233839/http:/www.jisc.ac.uk/whatwedo/programmes/vre.aspx) [cited 2017 Feb 20].

[http://webarchive.nationalarchives.gov.uk/20140702233839/http://www.jisc.ac.uk/whatwedo/programmes/vre.aspx](http://webarchive.nationalarchives.gov.uk/20140702233839/http:/www.jisc.ac.uk/whatwedo/programmes/vre.aspx).

[5] European Commission.EINFRA-9-2015. 2015 [[[cited 2017 Feb 20](http://www.vre4eic.eu/publications/press-releases/69-a-4-37m-european-investment-towards-next-generation-virtual-research-environments-for-70-000-researchers)]. <http://cordis.europa.eu/programme/rcn/664625_en.html>.

[6] Carusi A, Reimer T. Virtual research environment collaborative landscape study. London: Jisc; 2010. 106p. <https://spiral.imperial.ac.uk/bitstream/10044/1/18568/2/vrelandscapereport.pdf>.

[7] Candela, L, Castelli D. Pagano, P. Virtual Research Environments: An Overview and a Research Agenda. Data Science Journal. 2013, 12: GRDI75–GRDI81. DOI: [10.2481/dsj.GRDI-013](http://doi.org/10.2481/dsj.GRDI-013).

[8] [Texas Advanced Computing Centre. Agave Platform. 2016](http://agaveapi.co/) [[cited 2017 Feb 20].](http://www.vre4eic.eu/publications/press-releases/69-a-4-37m-european-investment-towards-next-generation-virtual-research-environments-for-70-000-researchers) <http://agaveapi.co>.

[9] Github. fli-iam/CARMIN. 2017 [[cited 2017 Feb 20].](http://www.vre4eic.eu/publications/press-releases/69-a-4-37m-european-investment-towards-next-generation-virtual-research-environments-for-70-000-researchers)[https://github.com/fli-iam/CARMIN](https://github.com/fli-iam/CARMI).

[10] Common Workflow Language. n.d. [[cited 2017 Feb 20].](http://www.vre4eic.eu/publications/press-releases/69-a-4-37m-european-investment-towards-next-generation-virtual-research-environments-for-70-000-researchers) [http://www.commonwl.org](http://www.commonwl.org/).

[11] Boutiques. Boutiques. 2015 [[cited 2017 Feb 20].](http://www.vre4eic.eu/publications/press-releases/69-a-4-37m-european-investment-towards-next-generation-virtual-research-environments-for-70-000-researchers) [http://boutiques.github.io](http://boutiques.github.io/).

[12] NIDM Working Group. Neuroimaging Data Model. n.d.[[cited 2017 Feb 20].](http://www.vre4eic.eu/publications/press-releases/69-a-4-37m-european-investment-towards-next-generation-virtual-research-environments-for-70-000-researchers) [http://nidm.nidash.org](http://nidm.nidash.org/).

[13] Brain Imaging Data Structure [[cited 2017 Feb 20].](http://www.vre4eic.eu/publications/press-releases/69-a-4-37m-european-investment-towards-next-generation-virtual-research-environments-for-70-000-researchers)n.d. <http://bids.neuroimaging.io/>

some of these issues, such as the

[14] IVOA.net. International Virtual Observatory Alliance. n.d. [[cited 2017 Feb 20].](http://www.vre4eic.eu/publications/press-releases/69-a-4-37m-european-investment-towards-next-generation-virtual-research-environments-for-70-000-researchers) <http://www.ivoa.net/>.

[15]CANARIE. Research Platforms. 2017 [cited 2017 Feb 20]. <https://www.canarie.ca/software/platforms/>.

[16]SGCI. About. 2015 [cited 2017 Feb 20]. [http://sciencegateways.org/about/.](http://sciencegateways.org/about/)

[17]NSF. Software Infrastructure for Sustained Innovation. 2016 Dec 5 [cited 2017 Feb 20] <https://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf17526>.

[18] Kacsuk P, editor. Science Gateways for Distributed Computing Infrastructures: Development framework and exploitation by scientific user communities. Springer, 2014.

[19] Ardizzone V, Barbera R, Calanducci A, Fargetta M, Ingrà E, Porro I, et al. The DECIDE Science Gateway. Journal of Grid Computing. 2012, 10: 689-707. DOI: [10.1007/s10723-012-9242-3](https://link.springer.com/article/10.1007%2Fs10723-012-9242-3#page-1).

[20] European Commission. Six new projects on e-Infrastructures for virtual research environments. 2015 [cited 2017 March 5].

<https://ec.europa.eu/programmes/horizon2020/en/news/six-new-projects-e-infrastructures-virtual-research-environments>

[21] [VRE4EIC. Sophia Antipolis, France – 1 February 2016. 2016 [cited 2017 Feb 20]. http://www.vre4eic.eu/publications/press-releases/69-a-4-37m-european-investment-towards-next-generation-virtual-research-environments-for-70-000-researchers](http://www.vre4eic.eu/publications/press-releases/69-a-4-37m-european-investment-towards-next-generation-virtual-research-environments-for-70-000-researchers)..

[22] Sci-GaIA. About Sci-GaIA. 2017 [cited 2017 Feb 20]. <http://www.sci-gaia.eu/about-sci-gaia/>.

[23]ICSG. International Coalition on Science Gateways[. n.d. [cited 2017 Feb 20].](http://www.vre4eic.eu/publications/press-releases/69-a-4-37m-european-investment-towards-next-generation-virtual-research-environments-for-70-000-researchers) <http://www.icsciencegateways.org/>.

[24]Research Data Alliance. VRE-IG[. n.d. [cited 2017 Feb 20].](http://www.vre4eic.eu/publications/press-releases/69-a-4-37m-european-investment-towards-next-generation-virtual-research-environments-for-70-000-researchers) <https://rd-alliance.org/groups/vre-ig.html>.

[25]International Workshop on Science Gateways. About IWSG[. n.d. [cited 2017 Feb 20].](http://www.vre4eic.eu/publications/press-releases/69-a-4-37m-european-investment-towards-next-generation-virtual-research-environments-for-70-000-researchers) <http://iwsg-life.org/site/iwsglife/>.

[26]International Workshop on Science Gateways. IWSG-A[. n.d. [cited 2017 Feb 20].](http://www.vre4eic.eu/publications/press-releases/69-a-4-37m-european-investment-towards-next-generation-virtual-research-environments-for-70-000-researchers) [http://iwsg-life.org/site/iwsglife/about-iwsg-a.](http://iwsg-life.org/site/iwsglife/about-iwsg-a)

[27] Gesing S, Wilkins-Diehr N. Science gateway workshops 2014 special issue conference publications. Concurrency and Computation: Practice and Experience,2015, 27: 4247–4251. DOI: [10.1002/cpe.3615](http://onlinelibrary.wiley.com/doi/10.1002/cpe.v27.16/issuetoc).

[28] Wilkins-Diehr N, Gesing S, Kiss T. Science gateway workshops 2013 special issue conference publications, Concurrency and Computation: Practice and Experience,2014: 253–257. DOI: [10.1002/cpe.3362](http://onlinelibrary.wiley.com/doi/10.1002/cpe.v27.2/issuetoc).

[29] [G](http://link.springer.com/article/10.1007/s10723-016-9389-4?wt_mc=Internal.Event.1.SEM.ArticleAuthorOnlineFirst)esing S., Wilkins-Diehr N., Barker M, Pierantoni G. Science gateway workshops 2015 special issue conference publications. Journal of Grid Computing. 2016, 14: 495-498. DOI: [10.1007/s10723-016-9389-4.](http://link.springer.com/article/10.1007/s10723-016-9389-4)

[30]Gesing, S., Wilkins-Diehr, N. Barker, M. HICSS-50 Minitrack on Science Gateways and Portals[. 2016 [cited 2017 Feb 20].](http://www.vre4eic.eu/publications/press-releases/69-a-4-37m-european-investment-towards-next-generation-virtual-research-environments-for-70-000-researchers) <http://scholarspace.manoa.hawaii.edu/handle/10125/42675>.

[31] IEEE. IEEE Technical Committee on Scalable Computing: Technical Area on Science Gateways. n.d.[[cited 2017 Feb 20].](http://www.vre4eic.eu/publications/press-releases/69-a-4-37m-european-investment-towards-next-generation-virtual-research-environments-for-70-000-researchers) [https://sites.google.com/site/ieeesciencegateways/home.](https://sites.google.com/site/ieeesciencegateways/home)

[32] Smith AM, Katz DK, Niemeyer KE. FORCE11 Software Citation Working Group. Software Citation Principles. PeerJ Computer Science. 2016, 2:e86. DOI: [10.7717/peerj-cs.86](https://doi.org/10.7717/peerj-cs.86)

[33] Madhavan K, Zentner L, Farnsworth V, Shivarajapura S, Zentner M, Denny N, Klimeck G. nanoHUB.org: Cloud-based Services for Nanoscale Modelling, Simulation, and Education. Nanotechnology Reviews, 2013 January, 2(1): 107–117, ISSN (Online) 2191-9097, ISSN (Print) 2191-9089. DOI: [10.1515/ntrev-2012-0043](https://www.degruyter.com/view/j/ntrev.2013.2.issue-1/ntrev-2012-0043/ntrev-2012-0043.xml).

[34] Mayernik MS, Hart DL, Maull KE, Weber NM. Assessing and tracing the outcomes and impact of research infrastructures. Journal of the Association for Information Science and Technology. 2016, July. DOI [10.1002/asi.23721](http://onlinelibrary.wiley.com/doi/10.1002/asi.23721/abstract).

[35] Beagrie N, Houghton J. The Value and Impact of the European Bioinformatics Institute. 2016 [cited 2017 Feb 20]. <http://www.beagrie.com/EBI-impact-report.pdf>.

[36] Hannay JE, MacLeod C, Singer J, Langtangen HP, Pfahl D, Wilson G. How Do Scientists Develop and Use Scientific Software. Proceedings of 2009 ICSE Workshop on Software Engineering for Computational Science and Engineering. IEEE CS, 2009: 1–8. DOI: [10.1109/SECSE.2009.5069155](http://dx.doi.org/10.1109/SECSE.2009.5069155).

[37] Lawrence KA, Zentner M, Wilkins-Diehr N, Wernert JA, Pierce M, Marru SM. Science gateways today and tomorrow: Positive perspectives of nearly 5,000 members of the research community. Concurrency and Computation: Practice and Experience.2015, 27(16): 4252-5268. DOI: [10.1002/cpe.3526](http://onlinelibrary.wiley.com/doi/10.1002/cpe.3526/abstract).

[38] Wiedmann T. An input–output virtual laboratory in practice. Economic Systems Research. 2017: 1-17. DOI: [10.1080/09535314.2017.1283295.](https://protect-au.mimecast.com/s/z4n0BMS6gkqRu2?domain=dx.doi.org)

[39] FORCE11. Software Citation Working Group. 2017 [cited on 2017 Mar 23]. <https://www.force11.org/group/software-citation-working-group>.

[40] Miller MA, Pfeiffer W, Schwartz T. The CIPRES Science Gateway: Enabling High-Impact Science for Phylogenetics Researchers with Limited Resources. Proceedings of the 1st Conference of the Extreme Science and Engineering Discovery Environment. 2012. DOI: [10.1145/2335755.2335836](http://sciencegateways.org/wp-content/uploads/2013/03/CIPRES-article-2012.pdf).