Estimating the value and impact of Nectar Virtual Laboratories

Report to Nectar

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1. Introduction

In 2016 the Victoria Institute of Strategic Economic Studies (VISES) at Victoria University was commissioned by the National eResearch Collaboration Tools and Resources project (Nectar) to estimate the value and impact of Nectar Virtual Laboratories (VLs).

Nectar provides an online infrastructure that supports researchers to connect with colleagues in Australia and around the world, allowing them to collaborate and share ideas and research outcomes, which will ultimately contribute to our collective knowledge and make a significant impact on our society.

It provides support for a network of 14 VLs which are domain-oriented online environments that draw together research data, models, analysis tools and workflows to support collaborative research across institutional and discipline boundaries.

Given the resources available and the central role of VLs in the Nectar project, it was agreed that the most appropriate approach to estimating the value and impact of Nectar was to concentrate on estimating the value and impact of 4 VLs, namely

- Biodiversity and Climate Change Virtual Laboratory (BCCVL)
- Characterisation Virtual Laboratory (CVL)
- Genomics Virtual Laboratory (GVL), and
- Humanities Networked Infrastructure (HuNI)

Most VLs funded by Nectar have only been active for a few years and are still in their growth stages. An evaluation of their overall impact and value might best be done from the perspective of some years in the future when the VLs are in a more mature growth phase. Therefore the analysis and conclusions drawn in this study should be treated as preliminary and depend significantly on the assumptions made about future growth paths.

It became clear during the course of this study that while VLs share many features in common, they differ significantly from each other in terms of the services they provided to their target communities. Furthermore they differ in how easy it is to express their value and impact in traditional economic terms. Consequently, we have adopted a number of quantitative and qualitative approaches to revealing value and impact and have used the Characterisation Virtual Laboratory as a case study to analyse this in more depth. Our approach to Humanities Networked Infrastructure (HuNI) has been exploratory in nature with the aim of identifying different approaches that might be more fully developed in a future study.

2. The Nectar project

Nectar has its origins in Commonwealth government initiatives to support national research infrastructure. The National Collaborative Research Infrastructure Strategy (NCRIS) was established by the Commonwealth Government in 2004 and currently provides funding for 27 active projects across 222 institutions employing over 1700 technical experts, researchers and facility managers. NCRIS facilities are used by over 35,000 researchers, both domestically and internationally and also attract funding from organisations in the higher education, government, non-profit and industry sectors (Department of Education 2017).

Since its establishment there have been a number of reviews and roadmaps of the NCRIS program.

The Strategic Roadmap for Australian Research Infrastructure, released in August 2008, updated a similar roadmap in 2006 but placed increased emphasis on eResearch

> "in recognition of the pervasive and underpinning relevance of ICT to research. As collaborative research increases, eResearch is providing the most influential and effective way of enabling institutions to work together, using shared infrastructure, resources and policies."[1]

In its 2009/10 Budget the Australian Government announced a Super Science Initiative to further support research infrastructure by addressing the priorities identified in the 2008 Strategic Roadmap. The Super Science Initiative was financed through the Education Investment Fund. Nectar was established in 2009 by the Australian Government following a 2009/10 Budget announcement of $47 million to support Nectar as part of the Super Science initiative financed by the Education Investment Fund (EIF), and subsequently received NCRIS funding. Nectar has received $61 million in government funding, matched by co-investment of $54 million from Australian universities and research organisations

The University of Melbourne is the lead agent for the administration of Nectar. Governance of Nectar is provided by the Nectar Project Board, chaired by Russell Yardley, with 9 other members drawn from participating research institutions.

The Nectar directorate comprises the equivalent of 6.5 full-time staff and is led by the Director, Associate Professor Glenn Moloney.

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[1] The roadmap further states that " a new capability in the Humanities, Arts and Social Sciences (HASS) has been identified in recognition of the wide ranging contributions these disciplines make to the national interest. Investment in this area would relate to a HASS eResearch infrastructure including data creation and digitisation of research materials". The Humanities Networked Infrastructure (HuNI) can be viewed as a response to this.

Nectar is an example of a science gateway which Shahand (2015) defines as a "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."

A recent review of science gateways (Barker et al 2017) describes their benefits as follows.

> *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 (including industry and 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. Any community member can download and use code and also contribute features, for example, via git pull requests.*

Nectar provides the majority of its funding through two main investment programs in e-research infrastructure:

- Virtual Laboratories
- Research Cloud

Virtual Laboratories

Nectar VLs are rich domain-oriented online environments that draw together research data, models, analysis tools and workflows to support collaborative research across institutional and discipline boundaries. They are built and led by the Australian research sector and are used nationally and internationally by the research community and other stakeholders, including industry.

Data analysis is increasingly an essential aspect of research in most academic disciplines, with large amounts of data requiring more storage and computing power than most desktop environments can provide. Virtual Laboratories can provide High Performance Computing (HPC) resources to analyse and store such data and provide training in advanced analytical methods needed to analyse large datasets.

Nectar VLs are hosted on remote servers and are accessible remotely, via the internet. Researchers no longer need to be physically co-located: any resources, including people, can be globally distributed. All that is needed is an internet connection for access to collaborators, data, computational and analytical tools.

Remote access to research resources increases the efficiency of research and expands its impact. The cost of HPC infrastructure can be shared – it no longer needs not be replicated in every research facility that requires it. The savings include costly upgrades that are needed every few years to maintain HPC. The VLs platform is well suited for delivering training in advanced analytical methods to update analytical skills and to train a new generation of researchers. Furthermore, VLs provide a platform for collaboration, enabling researchers to share ideas and research outcomes with colleagues in Australia and around the world, across institutional and discipline boundaries, ultimately expanding to our collective knowledge.

Once Nectar was established it initiated two Requests for Proposals for VLs in September 2010 and April 2012. Contracts with the institutions that proposed the successful VLs were signed from May 2012 to January2013.

Virtual Laboratories funded under Nectar recorded over 19,000 users in 2017 across 12 VLs, including, on average, users from over 20 international organizations and 30 Australian organizations (Barker et al 2017).

A complete list of VLs is given in Appendix 1.

Since their inception, access to the VLs and other services funded by Nectar has been free to users.

The four VLs considered in this study have received funding from Nectar as shown in Table 2.1.

Table 2.1 Funding for four VLs to 2016-17, $

	BCCVL	CVL	GVL	HUNI
Nectar cash				
to 2013-14	1,236,063	1,618,108	2,334,121	1,329,000
2014-15	220,000	320,000	445,000	193,000
2015-16	230,000	225,000	230,000	192,500
2016-17	177,000	177,000	177,000	120,000
Total	1,863,063	2,340,108	3,186,121	1,834,500
Partners				
Cash	600,000			
In-kind	1,315,971	1,836,740	2,917,707	2,500,000
Total	3,779,034	4,176,848	6,103,828	4,334,500

Nectar Cloud

Nectar Cloud provides computing infrastructure, software and services that allow Australia's research community to store, access, and run data, remotely, rapidly and autonomously. Nectar Cloud's self-service structure allows users to access their own data at any time and collaborate with others from their desktop in a fast and efficient way.

The Nectar Research Cloud is a single national cloud computing infrastructure, comprised of seven collaborating "nodes". Nodes procure hardware necessary for running the cloud compute, storage and network services.

Nectar is a world leader in deploying highly innovative cloud computing technology for the benefit of research – providing opportunities for federation with emerging international research clouds. The Nectar Research Cloud supports the NCRIS mission to deliver world class research facilities so that Australian researchers can solve complex problems in Australia and internationally.

3. Methodology

3.1 Approaches to estimating value and impact

The assessment of programs such as Nectar VLs, which provide free access to a range of web-based information technology databases, analysis software, training and other services, is a relatively new field and investigators have used a variety of approaches to estimate the value and impacts of these programs.

In a recent study of the value and impact of the European Bioinformatics Institute (EBI), a centre for research and services in bioinformatics, which is part of European Molecular Biology Laboratory (EMBL)., Beagrie and Houghton (2016) review the approaches taken by studies of science facilities. They note that most of these are of large scale infrastructure facilities such as synchrotrons, and only a few of data repositories and related infrastructure and services. They quote a review of studies by the group EvaRIO (Evaluation of Research Infrastructures in Open innovation and research systems) (2013) which found that cost-benefit analysis and techniques for estimating the return on R&D expenditure were relatively rare in the estimation of the value and impact of science facilities.

Beagrie and Houghton (2016) found that three main types of analysis were used in these studies: various forms of input-output analysis, case studies and examples, and forms of cost-benefit analysis using activity costing and/or contingent valuation as the basis of the analysis.

Input-output analysis is best suited to analysis of single site facilities such as a synchrotron while cases studies are limited in the extent to which the results can be scaled up or generalised.

Beagrie and Houghton therefore use a mixed method approach to cost-benefit analysis drawing upon their experience valuing a range of data services such as the National Crystallography Service at Southampton University and the UK Data Archive at the University of Essex (Beagrie et al. 2010), the UK Economic and Social Data Service (Beagrie, Houghton, Palaiologk, and Williams 2012), the UK Archaeology Data Services (Beagrie and Houghton 2013a), and the British Atmospheric Data Centre (Beagrie and Houghton 2013b).

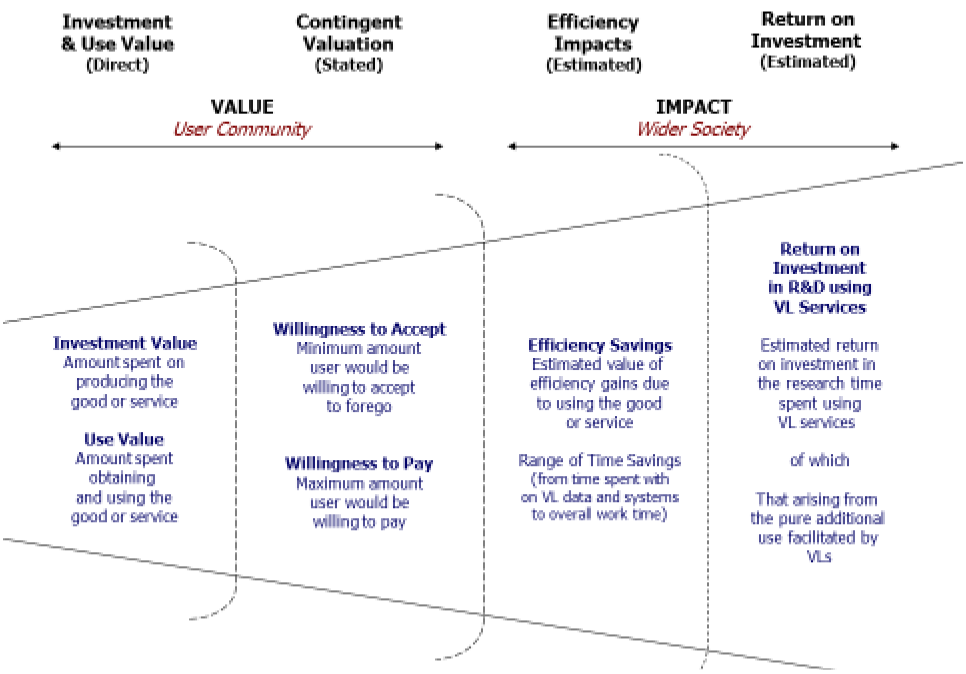
Again, in many respects, the services analysed in these studies are similar to Nectar VLs.

In studying the EBI and these other services, Beagrie and Houghton (2016) note that, because of their open access nature, they do not record much information about the users of the services, beyond what is available from IP addresses or web downloads when users access these services. They note further that more comprehensive and reliable data would improve economic analysis of these services.

Following these authors we have approached the task of measuring the value and impact of Nectar VLs in a number of ways.

These are shown in Figure 3.1. As with most large science facilities, the VLs provides value both to the user and to the wider society. The VLs provide a service to a community of researchers which can be valued in a several ways. These are discussed in more detail below but one is given by the value of the time spent using the service and another, a contingent valuation, is an estimate of its market value i.e. the value a user would place on the service if it was offered in the market place. In measuring the contribution to GDP, services with no market value, are often simply included at cost. However even where there is no monetary transaction it is possible to estimate a 'market' value of a service to a consumer. This market value is, the amount the consumer would either be willing to pay (WTP) to use it or accept (WTA) not to use it.

Figure 3.1 Impact valuation methodologies



Source: Beagrie, N. & Houghton, J.W. (2016) *The Value and Impact of the European Bioinformatics Institute* (www.beagrie.com/publications).

This willingness to pay or accept derives from the efficiency gains either from using the VL, or forgone from not using it, respectively. These efficiency gains can be separately estimated from data collected from VL users and provides a credibility check on the WTP and WTA estimates.

Beyond these sources of value, lie the returns to R&D which are derived from the value of the research outputs of the users of the VLs. These are more difficult to estimate but include significant social returns arising from spill overs, and other broader community benefits, from new innovative products sourced in part at least from the benefits gained from using the VLs.

1. Investment and use value

The investment value of a product is the amount of resources spent on its production and delivery. The use value on the other hand is the amount of resources spent by users on obtaining and using the product. Measures of the amount of time and money used by Nectar VL users in accessing and using the VL services is an indicator of the minimum amount that the service is worth to them.

Information about the resources involved in the discovery, access, and use of Nectar VL services can be obtained by user surveys and interviews.

2. Contingent valuation

Contingent valuation involves the assignment of monetary values to non-market goods and services based on preferences (i.e., Preference Theory). It is often used in the valuation of environmental and other assets, the services of which, in contrast to goods and services traded in the market place, are provided free or at nominal prices to users.

The usual measure of economic activity is Gross Domestic Product (GDP). This provides an aggregate value of goods and services traded in the market place in currency units. The value of these transactions is largely established through a price settled by demand and supply outcomes. However, there are widely acknowledged shortcomings with GDP as a measure of economic value (Stiglitz Commission 2008). One is measuring the value of services.

Services, particularly those provided by the public sector, are often included at cost because there is no direct demand and supply interaction between buyers and sellers. In economic terms, there is no mechanism whereby the consumer is able to *reveal her preferences* of how much she would be willing to buy at a particular price. This often means that services are undervalued in estimating GDP, because the users would be willing to pay significantly more than the cost of production if they were given that opportunity. This is likely to be the case for the Nectar virtual labs.

The value of the services provided by the VLs will be included in GDP largely based on the salary costs of operating the labs, when in fact; the value placed on the services by users may be significantly greater. The contingent valuation methodology provides one way of estimating this value.

If a good or service contributes to human welfare, it has economic value, and whether something contributes to an individual's welfare is determined by whether or not it satisfies that individual's preferences. Preferences are revealed by what an individual is willing to pay for a good or service and/or by the amount of time and other resources spent obtaining the preferred good or service. Where preferences are not revealed in the market, individuals can be asked what they would be willing to pay for, or to accept in return for being without, the good or service in a hypothetical market situation (i.e., stated preference). For a public good, the value is the sum of "willingnesses", as consumption is non-rivalrous (i.e., the same information can be consumed many times). The key difference between willingness to pay and willingness to accept is that the former is constrained by ability to pay (typically by disposable income), whereas the latter is not. Hence, willingness to pay directly measures the demand curve with a budgetary constraint, while willingness to accept measures the demand curve without a budgetary constraint (British Library 2004).

The contingent valuation approach involves asking what people would be willing to pay (to receive a benefit or remove a cost) or accept (to forgo a benefit or in compensation for a cost) if a market existed for the external effect. (Commonwealth of Australia 2006)

3. Efficiency impacts

Wider benefits and impacts can be explored by looking at the efficiency gains enjoyed by users and assigning an economic value to them, such as the value of time savings (productivity), and the avoidance of costs for users that would otherwise be involved in the creation/collection of the data for themselves or obtaining it elsewhere. For this we combine user survey questions about perceived efficiency impacts with activity costing.

4. Return on investment

There have been a number of studies both in Australia and overseas that have attempted to measure the returns to both public and private investment in research and development, and the contribution that R&D and technology development more broadly have made to economic growth.

The Productivity Commission has undertaken a number of large studies on the role of R&D in Australia (e.g. Industry Commission 1995, Shanks and Zheng 2006).

An analysis of the returns to health R&D by Access Economics (2008) found that health R&D provides returns to Australia of 117% per annum, with a benefit-cost ratio of 2.17. In an extension of this study in 2014. Deloitte Access Economics (2014) found that every dollar invested by the Medical Research Future Fund would generate returns of $3.39 in future health and productivity gains.

In examining these and other Australian and international studies, Beagrie and Houghton (2016) concluded that the returns to research and development were typically in the range of 20% to 60% per annum. In their analysis based on a methodology developed by Houghton and Sheehan (2009) and Houghton et al (2009) based on a modified Solow-Swan model of economic growth, they used a conservative value of 40%.

These and other studies of have consistently found large returns to investment in both public and private research and development.

Balanced Value Impact Model

In our discussions with the 4 VLs that are the focus of this study both HuNI and the GVL drew our attention to the Balanced Value Impact Model which is an evaluation schema developed by Professor Simon Tanner of King's College London (Tanner 2012). This publication is a manual for users to undertake these evaluations and the methodology is complex. From a brief review of the literature it does not appear to have been implemented fully in any evaluation to date.

We discuss the Balanced Value Impact Model in more detail in Section 7 below.

3.2 Survey data

Most of the approaches outlined above depend on how users use VL services and the value that can be put on this use.

A major limitation experienced with studies of the value and impact of research infrastructure such as Nectar VLs is the paucity of data relevant to the approaches outlined in the previous section. When commenting on these studies Beagrie and Houghton (2016) noted the variability of research infrastructure metrics and the implications for economic analysis and quoted from their review (Beagrie and Houghton 2014) as follows

> *It is also clear from these studies that different data centres collect financial and operational data, such as user statistics, data deposit, access and download statistics, to varying levels of detail and using different definitions. More guidance is needed on the collection of such data. Doing so would help to ensure a greater degree of standardisation of operational records across data centres. This would be of greatest benefit to funders investing in a range of data centres, and would provide more comprehensive and reliable data for economic analysis. There would be considerable advantage to providing guidance regarding the collection of such data as it is fundamental to the economic analysis and in making the business or funding case*.

Funders will need to ensure allowance is made in budgets to enable such centres to collect adequate information so that proper evaluations can be undertaken.

To address the potential limitations of usage data collected by Nectar VLs, and to provide data relevant to the approaches outlined above, an online survey questionnaire was developed to measure aspects of the user experience with VLs using the Qualtrics on-line software tool. (https://www.qualtrics.com/homepage/)

The starting point for the questionnaire was that used by Beagrie and Houghton (2016) but modified to address the situation of each VL. Draft initial survey questionnaires were developed by VISES and discussed with key Nectar and VL personnel. They were then refined iteratively over a number of discussion cycles and pilot tested.

The questionnaire used a range of standard survey approaches, including the use of "critical instances", such as the last data accessed/downloaded (for users). A number of questions sought specific information on: the time and cost of access for users; the benefits and efficiency impacts of access; and contingent valuation (i.e., willingness to pay or accept) using stated preference techniques. Answers to these questions were interpreted carefully, in the context of open-ended text comments in the survey. These quantitative questions were supplemented by qualitative questions asking for views on the importance and impact of the VL for users, to ensure that the quantitative and qualitative findings were in accord.

The surveys were progressively implemented from April to May 2017.

4. The Virtual Laboratories

4.1 Biodiversity and Climate Change Virtual Laboratory (BCCVL)

The Biodiversity and Climate Change Virtual Laboratory was formed under an agreement in November 2012 between Nectar and Griffith University. The other main partners in BCCVL are

- James Cook University
- University of New South Wales
- Macquarie University
- University of Canberra
- Atlas of Living Australia (ALA), an e-infrastructure funded by NCRIS
- Terrestrial Ecosystem Research Network (TERN), a national observatory for Australian ecosystems, delivering data streams that enable environmental research and management, with funding from NCRIS
- Queensland Cyber Infrastructure Foundation (QCIF) a HPC consortium of Queensland universities

Under the agreement, Nectar has provided funding of $1,863,063 to 2016-17and partners have committed to $600,000 in cash and $1,315,971 in-kind. The BCCVL web site was launched in August 2014.

The BCCVL project team of 8 people is located at Griffith University and headed by Mr Hamish Holewa. It has a Steering Committee of 17 people drawn from participating institutions and Nectar, as well as an Ecological Modelling Scientific Advisory Group of 8 people.

The Biodiversity and Climate Change Virtual Laboratory (BCCVL) is a “one stop modelling shop” that simplifies the process of biodiversity-climate change modelling. Its mission is to connect the research community to Australia’s national computation infrastructure by integrating a suite of tools in a coherent online environment where researchers can access data and perform data analysis and modelling.

Previously, the lines of inquiry into biodiversity and climate change impacts were stymied due to researchers’ inability to access a standardised set of tools for analysis and requisite data sources, and computational limitations.

The goal of the BCCVL is to integrate these tools and datasets with high-performance computers and major data storage facilities, thereby enabling more efficient investigation of biological systems and facilitating the development of additional research trajectories currently not possible due to computational limitations.

Central to the modelling facilitated by BCCVL is species distribution modelling, alternatively known as environmental niche modelling, (ecological) niche modelling, predictive habitat distribution modelling, or climate envelope modelling. It refers to the process of using computer algorithms to predict the distribution of species in geographic space on the basis of a mathematical representation of their known distribution in environmental space (= realised ecological niche). The environment is in most cases represented by climate data (such as temperature, and precipitation), but other variables such as soil type, water depth, and land cover can also be used. These models allow for interpolating between a limited number of species occurrence and they are used in several research areas in conservation biology, ecology and evolution.

Developing a species distribution model begins with observations of species occurrences: these are places where we know a species has been found. These occurrences are mostly point-based and come from sources such as museum records and observations of experts in the field. BCCVL users can upload their own species distribution data or access one or more of the many datasets provided by BCCVL.

To calibrate a correlative species distribution model two types of input data are needed: species occurrences, and measurements of a suite of environmental variables, such as temperature and rainfall. These two types of data are then put into an algorithm to find associations between the known occurrences of a species and the environmental conditions at those sites, to identify the environmental conditions that are suitable for a species to survive. This provides information about where species occur and something about the environmental conditions of those places. The algorithm uses these two types of information to estimate the probability of a species occurring in a place as some function of the environmental conditions of that place.

BCCVL currently supports 17 different types of species distribution algorithms.

BCCVL also offers a range of climate change models that can be used in conjunction with species distribution modelling to estimate the impact of climate change on species distribution.

The BCCVL web site offers a Knowledge Base which can guide users through the modelling process by providing information about the steps involved in modelling and the databases and other resources available.

The web site also offers a training course of 10 modules explaining SDM, the choice of algorithms and how to interpret modelling results.

BCCVL offers workshops aimed at academics and industry professionals, for instance HDR students, environmental/climate scientists and researchers, ecologists, decision-makers, members of government and industry groups. It also provides workshops for undergraduate students studying in areas such as ecology, environmental science, sustainability, climate change impacts, biology, flora and fauna, animal behaviour, planning and development, and conservation.

4.2 Characterisation Virtual Laboratory (CVL)

The Characterisation Virtual Laboratory (CVL) was formed under an agreement in May 2012 between Nectar and Monash University. Founding partners in CVL are

- Australian Microscopy and Microanalysis Research Facility
- Australian Nuclear Science and Technology Organisation
- Australian Synchrotron
- National Imaging Facility
- Australian National University
- University of Sydney
- University of Queensland

Through its life, a number of project partners have joined the CVL and engaged directly through project funding:

- CSIRO
- Deakin University
- Intersect, and its partners
- QCIF, and its partners
- RMIT
- The Pawsey Supercomputing Centre
- The Terrestrial Ecosystem Research Network
- University of Melbourne
- University of New South Wales
- University of Western Australia
- VicNode, and its partners

Under the agreement, Nectar has provided funding of $2,340,108 to 2016-17 and partners have committed to $1,836,740 in-kind.

The CVL web site was launched in March 2013.

The predominant practise of the CVL project is to work with instrument facilities to provide data capture, analysis and visualisation services and thereby underpin the facility user community.

CVL has worked with or is working with 26 facilities to integrate over 100 instruments with a total value of around $250 million.. A complete list of these facilities is given in Appendix 2.

The Characterisation Virtual Laboratory (CVL) aims to integrate Australia's imaging equipment with specialised High Performance Computing capabilities and with data collection nodes and provide scientists with a common environment for analysis and collaboration. It initially developed four research application ('drivers') in multi-modal or large-scale imaging in neuroscience, structural biology, atom probe and X-ray science, and through partnership, this has been extended to cytometry, neutron-beam imaging, light microscopy, and bioinformatics.

Each driver is led by a world-class research group, is supported by an Australian research consortium and is in a national research priority area. The results from this development are distributed to the community through CVL "Workbenches".

CVL users have the option of using the computing resources on the Nectar research cloud or accessing MASSIVE (Multi-modal Australian ScienceS Imaging and Visualisation Environment) the HPC facility joint venture between Monash University, CSIRO and the Australian Synchrotron

An important role for CVL has been to establish the capability within imaging sites for automatic capture and storage of imaging data to the cloud. This enables users to be able to access their imaging data through the CVL web site and to perform analysis using the software tools provided by CVL based around the MyTardis and Store.Monash tools (Ceguerra et al 2013).

CVL has developed a number of applications that are reused across a range of Australian facilities. These include: extensions to the MyTardis data management platform to support instrument facilities; an instrument integration app, called MyData to make integration quicker, simpler and less reliant on specialist IT support; and Strudel, a tool that makes accessing remote analysis environments easier.

4.3 Genomics Virtual Laboratory (GVL)

The Genomics Virtual Laboratory was formed under an agreement in May 2012 between Nectar and the University of Queensland. The other main partner in GVL is the University of Melbourne. The following organisations are partners or collaborators with GVL

- The University of Queensland
- QFAB Bioinformatics
- Queensland Cyber Infrastructure Foundation
- Melbourne Bioinformatics (formerly Victorian Life Sciences Computation Initiative) Victorian eResearch Strategic Initiative
- The University of Melbourne
- Baker IDI Heart and Diabetes Institute
- Peter MacCallum Cancer Centre

- The Garvan Institute of Medical Research
- Victor Chang Cardiac Research Institute
- CSIRO
- Bioplatforms Australia
- Monash University
- The University of Sydney
- The University of Western Australia
- Australian Bioinformatics Network
- EMBL Australia
- Australian Genome Research Facility
- Australian National Data Service

Under the agreement, Nectar has provided funding of $3,186,121 to 2016-17 and partners have committed to $2,917,707 in-kind.

The GVL is administered by Melbourne Bioinformatics. It has a staff of 8 led by Associate Prof Andrew Lonie, as Director of Melbourne Bioinformatics.

The Genomics Virtual Laboratory provides a cloud-based suite of genomics analysis tools for life science research and training.

Biologists without computer science training can go straight to a user-friendly platform which hosts a suite of tested bioinformatics tools and pipelines for fast, consistent, data analysis. The platform is constantly updated to have the latest features in use by expert bioinformaticians. Adopted both locally and overseas, the GVL has already been recognised as a quality platform to help address the shortage of bioinformatics expertise around the world and manage the complex, multiple-layered data analysis tasks confronting life scientists today.

Nationally and internationally it is being used both by life scientists working with genomic data and academics teaching bioinformatics at undergraduate and post-graduate levels.

Life scientists without access to bioinformatics expertise are the primary users of the GVL. Practising bioinformaticians who know how to find the right tool for the data analysis job, find that the GVL is working for them in other ways. Small bioinformatics groups or lone practitioners use the GVL to train their local teams to do their own simple bioinformatics tasks on the GVL, freeing up capacity to work on more complex research problems or to collaborate more broadly.
The GVL web site is built around Galaxy, an open, web-based platform for data intensive biomedical research. Galaxy is an international collaborative project managed by the Center for Comparative Genomics and Bioinformatics at Penn State University, and the Department of Biology at Johns Hopkins University.

Users of GVL have the option of launching their own private server on a public or private cloud, with the GVL pre-installed, or accessing it through one of the public GVL services on the GVL web site managed by GVL. Most users without relevant IT skills use one of three main public services namely

- Galaxy Melbourne
- Galaxy Queensland
- Galaxy Tut

Galaxy Tut is used for training purposes. As well, the GVL provides on-line basic and advanced Galaxy tutorials and command line tutorials which give step by step instructions for an example analysis. Protocols outline the analysis methods and suggest and compare tools for each step rather than prescribe them.

GVL users typically load genomic sequences that are then manipulated and analysed using a comprehensive suite of tools.

Aside from the public services managed by the GVL, a number of other institutions such as CSIRO and La Trobe University have downloaded the GVL to their servers to locally manage access for their institutional users.

4.4 Humanities Networked Infrastructure Virtual Laboratory (HuNI)

The Humanities Networked Infrastructure Virtual Laboratory (HuNI) was formed under an agreement with Deakin University in May 2012. Nectar has contributed funding of $1,834,500 to 2016-17 and partners have committed to $2,500,000 in-kind.

The partners in HuNI have included

- Australian Institute of Aboriginal and Torres Strait Islander Studies (AIATSIS)
- Australian National University
- Deakin University
- Flinders University
- Intersect Australia
- Macquarie University
- RMIT University
- University of Melbourne
- University of New South Wales
- University of Queensland
- University of Sydney
- University of Western Australia
- V3 Alliance
- National Library of Australia

- Australian Centre for the Moving Image (ACMI)

The Project Director of HuNI is Professor Deb Verhoeven at Deakin University.

Google Analytics data provided by HuNI indicates around 4,600 users of HuNI during 2016.

HuNI (Humanities Networked Infrastructure) combines data from many Australian cultural websites into a large humanities and creative arts database. HuNI data covers all disciplines and brings together information about the people, works, events, organisations and places that make up the country's rich cultural landscape.

HuNI combines information from 32 of Australia’s most significant cultural datasets. These datasets comprise more than 17 million authoritative records relating to the people, organisations, objects and events that make up Australia's rich cultural heritage. HuNI also enables researchers to work with and share this large-scale aggregation of cultural information. HuNI has been developed as a partnership between 16 public institutions, led by Deakin University.

Access to the HuNI web site was first available in July 2012 and was officially launched in October 2014.

As Verhoeven and Burrows 2015 suggests this places HuNI

> ‘somewhere between a “data warehouse” in which the incoming data are first cleaned and organised into a consistent schema and a “data lake” in which the incoming data are ingested in their raw form and the responsibility or making sense of the data lies entirely with the end user’ p418

The constituent databases, have been reconfigured by HuNI so that the records are mapped to six core entities: Person, Organization, Event, Work, Place, and Concept. (Verhoeven and Burrows 2015).

The user begins their search for an item of interest in one of these entities. That could be a name of a person or a particular organisation or a concept (topic) of interest. The power of HuNI is to retain as data within HuNI the connections discovered between items in the entities, such as a connection linking a person to others and/or an organisation and a concept etc. made by the user. These are saved by the user and may be placed in the public domain and thus made available for other users. Subsequent users may dispute the links made or supplement the links, creating a richer set of networks connected to one or more of the entities.

An example of such a network (a HuNI Knowledge Graph) is shown in Figure 4.1.

This graph shows links related to the collection: Australian Fashion 1850-1950, including related persons and works. In particular it links the Australian Fashion Collection via a 1938 film with a fashion theme, *Dad and Dave Come to Town* to a collection generated by a different HuNI user investigating works directed by Ken Hall and produced by Cinesound Productions. There are further links made to other films directed by Ken Hall. By tracing the pathway of these visual links a HuNI user is able to expand their discovery opportunities through the serendipitous connections provided by a multitude of HuNI users.

Figure 4.1 An example of a HuNI Knowledge Graph

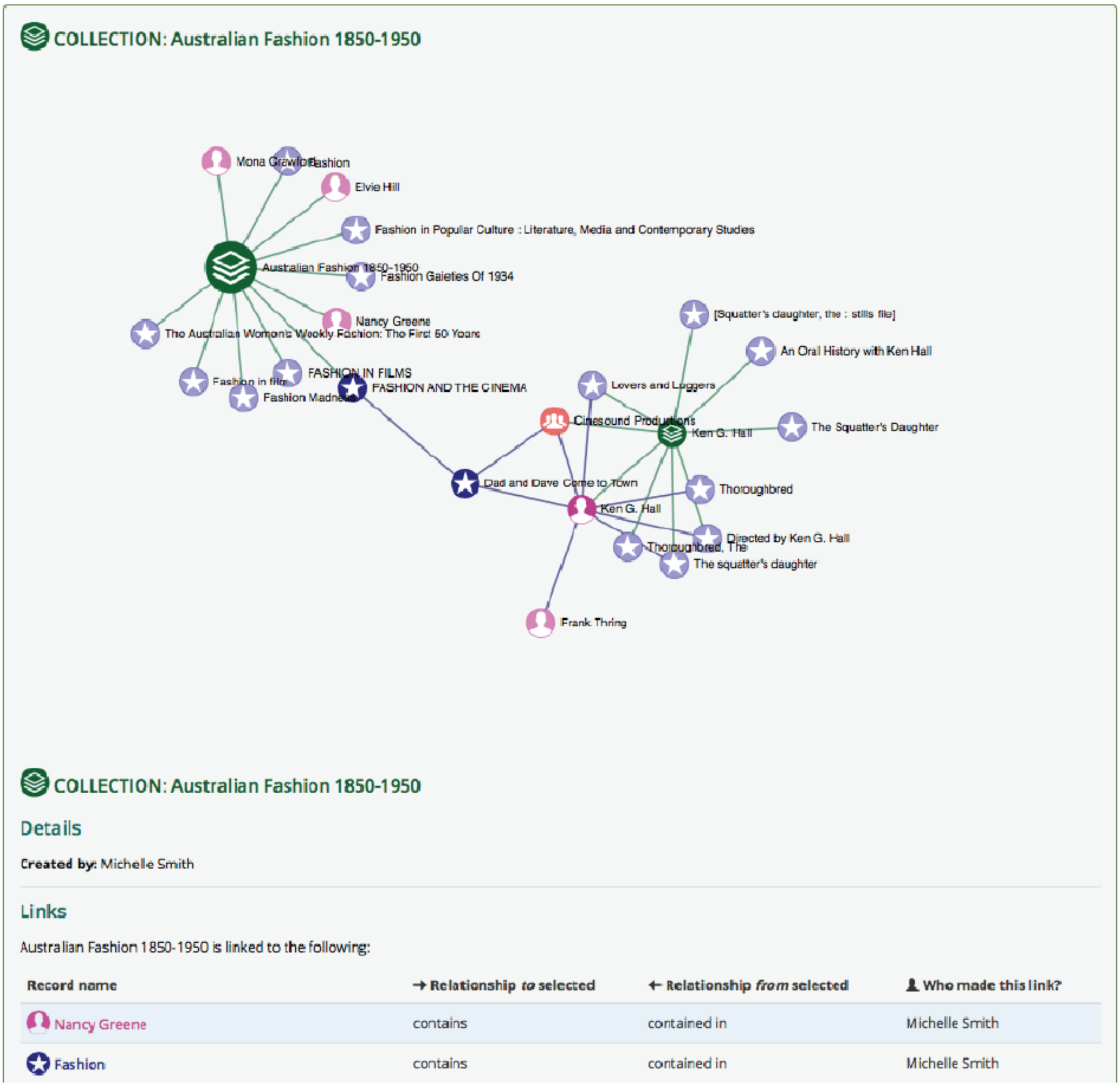


FIGURE 4. A screenshot of the HuNI Knowledge Graph showing user-generated links between two collections as both semantic and navigable elements. (Deb Verhoeven et al., http://dx.doi.org/10.6084/m9.figshare.2008905. Accessed October 28, 2015).

Source Verhoeven 2016, p 23

As the figure below illustrates, this process converts isolated data and information to knowledge by capturing the relationships arising from the expertise of HuNI users. The knowledge created by these connections is further enriched through the collaboration of other humanities users of the website.

Figure 4.2 Connections between data and information using HuNI

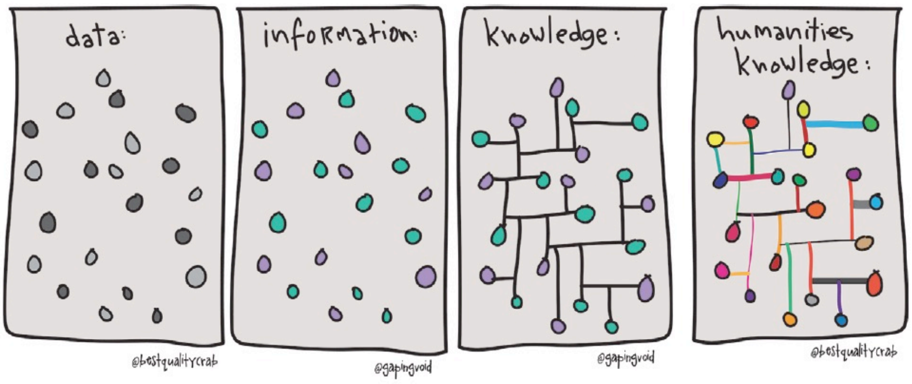


FIGURE 3. “Rich connectivity” in the humanities. (Deb Verhoeven, http://dx.doi.org/10.6084/m9.figshare.1397453. Created April 29, 2015; accessed October 28, 2015.)

Source Verhoeven 2016, p 13

This facilitation of an unstructured approach to knowledge creation within the database encourages a serendipitous relationship search process. This is seen as a major added value of the VL, one that is particularly applicable to the humanities style of research and one that is not catered for by conventional archival databases.

> ‘HuNI moves beyond thinking of serendipity as only a technical problem and instead treats it as a matter of social, philosophical, and political significance’ (p23 Verhoeven 2016).

HuNI has been established with the idea that valuable knowledge and new perspectives are buried in traditional archival databases, which can be released by the partly unanticipated search processes supported and used by HuNI users (Verhoeven 2016). Perhaps this creation of new connections is HuNI’s highest value. It not only facilitates the creation of new networks through links with multiple databases, but also has the software that allows the connections made in the search process to be recorded, stored and made available to other researchers. Over time that archive of these HuNI Knowledge Graphs will add significant value to the HuNI project.

At this stage the resources available to the project have been largely devoted to the development of the software that facilitates the characterisation of the underlying archival data bases in terms of searchable entities. The facility to store user developed connections is still in its infancy. A new system upgrade, including a new user interface, is about to be installed, which will better facilitate the creation, storage and searching of valuable HuNI Knowledge Graphs.

HuNI's value lies in the increasing participation of its users. The more links and collections that are made in HuNI, the more valuable a tool it becomes for everyone. This means that early on the benefit versus effort for HuNI users is relatively low, this rises exponentially as more users add their expertise to the platform. Investment in the promotion of HuNI and building of the community is required to ensure HuNI moves past the tipping point of users "getting more out of HuNI than they put in".

5. Data on usage of Nectar Virtual Laboratories

The methodologies for measuring the value and impact of Nectar's VLs depend on being able to describe the extent to which the VLs have been able to attract users of their services. In the evaluations we rely on data provided by the VLs on usage and on the responses to the on-line surveys of users.

Although the VLs differ in the extent and type of data they capture about usage of VL services, they readily provided usage data based on the regular collections they make for monitoring purposes and in response to further requests for different or more detailed data. Their ability to provide this data was limited for some because it was not data that was usually collected in the course of their operations.

The tables and figures below summarise the usage of VL services generally from when they became active to the present. For some, very early data was not available and the most recent data was for early 2017.

It is clear that the number of users for a particular VL increases rapidly in the first few years and has continued to grow over the past year.

This study on the value and impact of VLs is therefore occurring relatively early in their lifetimes, presenting challenges in assessing the likely number of users over the next few years and the potential maximum number of users. It is difficult to assess what percent of the current research base represents the maximum achievable by each VL and when this will occur. It would be expected that once this occurred, the future rate of growth would be lower and just reflect the numbers of new researchers entering the research fields of relevance to the VL.

BCCVL

BCCVL provided monthly usage data from June 2015 to March 2017. From this data we show in Table 5.1 the numbers of new users for each calendar year and the cumulative number of users at December of each year. To this we add estimates of the new users and cumulative users calculated as follows.

Over the 11 months to March 2017, the number of users increased by 3.75 times compared to the previous 11 months. If it is assumed that the number of new users in 2017 will be 2.0 times that in 2016, and the value in 2018 will be 1.5 times 2017, and with the same number of new users in 2019 and 2020 as in 2018, then the number of new users and the cumulative number of users for 2017 to 2020 will be as in Table 5.1.

These growth assumptions suggest that the cumulative number of users by December 2020 will be 11,246.

Table 5.1 BCCVL activity measures

	New users	Cumulative at December
2015	254	254
2016	916	1,170
2017	1,832	3,002
2018	2,748	5,750
2019	2,748	8,498
2020	2,748	11,246

CVL

CVL consulted with a range of imaging facilities partners and provided estimates of the number of users. To August 2017 this amounted to 2558, so we assume that the number at December 2016 was 2400. Based on an initial cohort of 101 at December 2012, we interpolated the number of new users from 2012 to 2016 and estimated that this would grow by 10% in the years to 2020. This resulted in an estimate of the cumulative total of 6,485 by the end of December 2020 (Table 5.2).

Table 5.2 CVL activity measures

	New users	Cumulative at December
2012	101	101
2013	300	401
2014	500	901
2015	700	1,601
2016	800	2,401
2017	880	3,281
2018	968	4,249
2019	1,065	5,314
2020	1,171	6,485

GVL

GVL has provided usage data for the three major public service portals. It has not been possible to obtain and activity data for those organisations and individuals that have downloaded the data and launched their own private server on a public or private cloud, with the GVL pre-installed.

GVL provided monthly usage data for Galaxy– Queensland for the period December 2013 to February 2017. The data for Galaxy– Melbourne covered September 2015 to February 2017 and for Galaxy– Tut it was December 2012 to February 2017.

The numbers of new users and the cumulative numbers of users at December for the three portals is shown in Table 5.3. In a similar manner to that used for BCCVL, we estimate the number or new users and cumulative users to 2020 but recognise that the 3 portals have been operating for different lengths of time.

For Galaxy– Queensland and Galaxy– Tut we assume a 10% growth in new users for each of the years 2017 to 2020. For Galaxy– Melbourne the number of new users in the 9 months to February 2017 was 2.6 times that of the previous 9 months. We assume that the number of new users in 2017 will be 2.5 times that of 2016, the numbers in 2018 will be 2.0 times that of 2017, the numbers in 2019 will be 1.5 times that of 2018 and the numbers in 2020 will be the same as 2019. The estimated new users and cumulative users at December each year are shown in Table 5.3.

Table 5.3 GVL activity measures

	Galaxy -Queensland		Galaxy -Melbourne		Galaxy -Tut	
	New users	Cumulative at December	New users	Cumulative at December	New users	Cumulative at December
2012					40	40
2013	27	27			117	157
2014	285	312			1,060	1,217
2015	586	898	65	65	510	1,727
2016	631	1,529	408	473	587	2,314
2017	694	2,223	1,020	1,493	646	2,960
2018	764	2,987	2,040	3,533	710	3,670
2019	840	3,826	3,060	6,593	781	4,451
2020	924	4,750	3,060	9,653	859	5,311

6. Estimating the value and impact of Nectar Virtual Laboratories

Most of the calculations reported in this section rely on estimates of the time spent by users accessing VL services and the salaries of these users.

6.1 Cost data

For academic users we have calculated the hourly rate for different academic positions by obtaining salary data from Monash University and calculating the value for 2017. The annual salaries shown in Table 6.1 are averages of the levels within each academic grade for these positions. We have checked these levels with those in a number of other universities and other sources of information and regard the Monash University values as representative of salaries within Australian universities. For comparison purposes, the salaries are around 5% higher than those for Victoria University. To obtain an hourly costs equivalent we divide the annual salaries by the average number of working days in a year (225) and by the number of hours worked per day (7.35).

Following Beagrie and Houghton (2016) we add 30% to this to account for non-wage labour costs. This is also in line with current Australian university guidelines. The indicative hourly costs calculated in this way are shown in Table 6.1.

For student and other users the starting point is the median starting salaries of bachelor degree graduates in 2015 published by Graduate Careers Australia Ltd. Their most recent data is for 2015. To estimate the values for 2017, we add a further 4.4%, being the estimated two year increase in average weekly earnings for full-time adults (ABS 2017).

Hourly costs are calculated in the same way as for academic hourly costs and these are shown in Table 6.2. From this we assume that the hourly cost for students is the hourly graduate cost of $44.52

Table 6.1 Academic salaries, and hourly costs

Level	Salary, 2017	Hourly salary, 2017	Hourly costs, 2017
	$,000	$	$
Academic A	77,819	47.06	61.17
Academic B	102,469	61.96	80.55
Academic C	123,546	74.71	97.12
Academic D	145,211	87.81	114.15
Academic E	178,005	107.64	139.93

Table 6.2 Annual graduate salaries and hourly costs

Qualification	Salary, 2015	Salary, 2017, est.	Hourly salary, 2017, est.	Hourly costs, 2017, est.
	$,000	$,000	$	$
Agricultural Science	50.0	52.2	31.56	41.03
Biological Sciences	50.0	52.2	31.56	41.03
Computer Science	54.0	56.4	34.09	44.32
Earth Sciences	60.0	62.6	37.88	49.24
Engineering	60.0	62.6	37.88	49.24
Mathematics	60.0	62.6	37.88	49.24
Physical Sciences	50.0	52.2	31.56	41.03
Veterinary Science	50.0	52.2	31.56	41.03
Average	54.3	56.6	34.25	44.52
TOTAL (all qualifications)	54.0	56.4	34.09	44.32

Source: Table 1: Median starting salaries of bachelor degree graduates in first full-time employment and aged less than 25, by field of education and sector of employment, 2015 ($,000, n)¤†, Graduate Careers Australia Ltd, Graduate Salaries Report 2015, Graduate Careers Australia Ltd, 2016 at http://www.graduatecareers.com.au/research/researchreports/graduatesalaries/

In the on-line survey of users, participants were asked about their position within their organisation. Allocating both academic and graduate level to these positions and using the distribution of answers from respondents, we calculated a mean hourly cost of users based on the hourly costs in Tables 6.1 and 6.2.

For BCCVL, CVL and GVL the hourly cost of users were $74.82 (or $63,127 annually), $66.39 ($56,015 annually) and $71.02 ($59,925 annually) respectively.

Investment value

In their study of EBI, Beagrie and Houghton were unable to estimate the total value of all the components of EBI's investment value, such as data acquisition, depositing data, collaboration cost and adding value to the data. They relied therefore on an estimate of the average annual operating expenditure as a proxy.

The set up and operating costs of each VL to the year 2016-17 were described in Table 2.2 in Section earlier.

If we assume that the annual operating expenses of each VL is equal to the average of the years 2014-15 to 2016-17 as shown in Table 2.2 and we apply that to each year out to 2020, we can calculate the estimated accumulated cost of each VL to 2020. This is shown in table 6.3 and is the estimated investment value of each VL.

Dividing this by the number of years from VL inception to 2020, we can calculate the annual value of the overall investment made in each VL. As can be seen from Table 6.3 this is in the range $550,000 to $600,000 for BCCVL, CVL and HuNI and is somewhat higher at about $870,000 for GVL.

Table 6.3 Estimated total and annual cost for Virtual Laboratories

	BCCVL	CVL	GVL	HUNI
Total costs to 2016-17	3,779,034	4,176,848	6,103,828	4,334,500
Average annual operating cost	209,000	240,667	284,000	168,500
Total costs to 2020	4,406,034	4,898,848	6,955,828	4,840,000
Annual value of total costs to 2020	550,754	612,356	869,479	605,000

Contingent valuation

The contingent value of a non-market good or service is the amount users are willing to pay for it and/or are willing to accept in return for giving it up. For a public good the value is the sum of willingnesses, as consumption is non-rivalrous (e.g., the same information can be consumed many times). The key difference is that the amount that users are willing to accept in return for giving up access is typically higher than the amount they would be willing to pay, primarily because the latter is constrained by what they can afford (e.g., by disposable income, limited research grants, etc.).

BCCVL

For BCCVL, the mean amount that users were willing to pay for access to BCCVL services was $1,154 (median value $250). On the other hand the mean amount users would be willing to accept to forego BCCVL services was $10,005 (median value $5,000). Users naturally put a higher value on BCCVL services when they are not subject to an income constraint. As a comparison, Beagrie and Houghton found the mean willingness to pay for EBI was around $2,800 (GBP 1628).

Using the mean willingness to pay value of $1,154, the contingent valuation of BCCVL by users would therefore have been $1,350,180 in the period to December 2016, or an annual equivalent of $852,745, rising to $13.0 million by December 2020, or $2.3 million per year. (Table 6.4). The annual equivalent for each year is calculated by dividing the cumulative value to that point by the number of months elapsed since inception of the VL and multiplying by 12. As usage of BCCVL began in June 2015, the annual value estimated for 2015 is higher than the cumulative value.

Using the higher value measured by users' willingness to accept, the contingent valuation of BCCVL would be $112.5 million by December 2020 or $20.1 million per year.

Table 6.4 BCCVL contingent valuation

	Cumulative users	WTP		WTA	
		Cumulative	Annual	Cumulative	Annual
2015	254	293,116	502,485	2,540,000	4,354,286
2016	1,170	1,350,180	852,745	11,700,000	7,389,474
2017	3,002	3,464,308	1,341,022	30,020,000	11,620,645
2018	5,750	6,635,500	1,851,767	57,500,000	16,046,512
2019	8,498	9,806,692	2,139,642	84,980,000	18,541,091
2020	11,246	12,977,884	2,324,397	112,460,000	20,142,090

CVL

The mean amount that CVL users were willing to pay was $1,524 (median $900), while their mean willingness to accept was $14,130 (median $20,000).

Using the mean value of $1,524 and the estimates of CVL users above, suggests that by December 2020 the contingent value of CVL would be $9.9 million or an average annual value of $1.2 million. Using the willingness to accept value this would be $91.6 million by December 2020, or $11.5 million annually (Table 6.5).

Table 6.5 CVL contingent valuation

	Cumulati ve users	WTP		WTA	
		Cumulative	Annual	Cumulative	Annual
2013	301	611,124	611,124	5,666,130	5,666,130
2014	601	1,373,124	686,562	12,731,130	6,365,565
2015	1,051	2,439,924	813,308	22,622,130	7,540,710
2016	1,550	3,659,124	914,781	33,926,130	8,481,534
2017	2,100	5,000,244	1,000,050	46,360,530	9,272,106
2018	2,705	6,475,476	1,079,246	60,038,370	10,006,395
2019	3,371	8,098,231	1,156,890	75,083,994	10,726,286
2020	4,103	9,883,262	1,235,410	91,634,180	11,454,271

GVL

The mean amount that Galaxy - Melbourne users were willing to pay was $606 (median $100), while their mean willingness to accept was $1285 (median $800).

Using the mean value of $606 and the estimates of all GVL users above, suggests that by December 2020 the contingent value of GVL would be $11.9 million or an average annual value of $1.9 million. Using the willingness to accept value this would be $25.3 million by December 2020, or $4.0 million annually (Table 6.6).

Table 6.6 GVL contingent valuation

	Cumulative users	WTP		WTA	
		Cumulative	Annual	Cumulative	Annual
2013	184	135,744	284,167	287,840	602,566
2014	1,529	926,574	528,529	1,964,765	1,120,726
2015	2,690	1,630,140	718,806	3,456,650	1,524,200
2016	4,316	2,615,496	858,905	5,546,060	1,821,276
2017	6,676	4,045,535	1,070,515	8,578,403	2,269,986
2018	10,190	6,174,885	1,363,932	13,093,610	2,892,166
2019	14,871	9,011,667	1,684,004	19,108,898	3,570,867
2020	19,714	11,946,691	1,901,364	25,332,505	4,031,769

Efficiency impacts

In the on-line surveys, users were asked the following questions about the amount of time they spent doing research, the share of that time working with data and their estimates of the time savings from using the VL.

> *Over the last twelve months, on average how many hours per week did you spend on research?*
>
> *Can you estimate the approximate share of your total research working time spent with data during the last twelve months (e.g. creating, manipulating and analysing data)?*
>
>> *All data:*
>>
>> *approximate percent of my total research working time*
>>
>> *Data from GVL:*
>>
>> *approximate percent of my total research working time*
>
> *To what extent, if any, has your use of GVL services and resources changed your research efficiency (i.e. the time saved compared to the situation if GVL did not exist?*

The time spent on research expressed in hours per week is shown in Table 6.7 for each VL.

Using the average annual cost per user calculated in Section 6.1, the values in Table 6.7 can be used to calculate the annual cost per user of (i) the time spent on research, (ii) the time spent working with data, (iii) the time spent working with VL, and (iv) the resulting increase in research efficiency. The results of these calculations can be seen in Table 6.7. The average annual value per user of the efficiency impact of BCCVL, CVL and GVL are $11,898, $13,240 and $23,431 respectively. As a comparison, Beagrie and Houghton found that EBI would be worth GBP 26,000 or $44,828 per person per annum.

Applying these values to the cumulative number of users for each VL we estimate that the efficiency improvement due to each VL is as shown in Table 6.9. More conservatively, if we apply these values just to the number of new users each year for each VL, the calculated values are as shown in Table 6.10.

Whichever method is used demonstrates that there are substantial benefits in research efficiency arising from the VLs.

Table 6.7 Survey responses on research and efficiency

		BCCVL	CVL	GVL
Time spent on research, hours per week	mean	22.8	28.5	37.9
	median	20.0	30.0	40.0
Share of research time working with data, %	mean	65.1	59.9	66.4
	median	70.0	50.0	75.0
Share of research time working with VL, %	mean	11.8	28.0	11.4
	median	5.0	23.0	7.0
Increase in research efficiency, %	mean	31.0	31.1	39.1
	median	30.0	30.0	50.0

Table 6.8 Average annual value of efficiency impact per user

		BCCVL	CVL	GVL
Annual costs		63,127	56,015	59,925
Annual cost of time spent on research	mean	38,381	42,572	59,925
	median	33,668	44,812	59,925
Annual cost of research time working with data	mean	24,986	25,500	39,790
	median	23,567	22,406	44,944
Annual cost of research time working with VL	mean	4,529	11,920	6,831
	median	1,683	10,307	4,195
Increase in research efficiency	mean	11,898	13,240	23,431
	median	10,100	13,444	29,963

Table 6.9 Value of Virtual Laboratories on research efficiency, using cumulative users, $

	Cumulative			Annual average		
	BCCVL	CVL	GVL	BCCVL	CVL	GVL
2013	0	5,309,154	4,311,244	0	5,309,154	4,311,234
2014	0	11,929,046	35,825,502	0	5,964,523	17,912,707
2015	3,022,137	21,196,896	63,028,516	1,007,386	7,065,632	21,009,454
2016	13,920,867	31,788,724	101,126,793	3,480,241	7,947,181	25,281,636
2017	35,718,327	43,439,735	156,423,186	7,143,715	8,687,947	31,284,560
2018	68,414,518	56,255,846	238,758,578	11,402,498	9,375,974	39,792,999
2019	101,110,708	70,353,569	348,437,568	14,444,486	10,050,510	49,776,673

2020	133,806,898	85,861,065	461,912,327	16,725,977	10,732,633	57,738,899

Table 6.10 Value of Virtual Laboratories on research efficiency, using new users, $

	Cumulative			Annual average		
	BCCVL	CVL	GVL	BCCVL	CVL	GVL
2013	0	3,971,935	3,374,009	0	3,971,935	3,374,009
2014	0	6,619,892	31,514,180	0	3,309,946	15,757,090
2015	3,022,158	9,267,849	27,202,947	1,007,386	3,089,283	9,067,649
2016	10,898,805	10,591,828	38,098,184	2,724,701	2,647,957	9,524,546
2017	21,797,610	11,651,011	55,296,257	4,359,522	2,330,202	11,059,251
2018	32,696,415	12,816,112	82,335,190	5,449,402	2,136,019	13,722,532
2019	32,696,415	14,097,723	109,678,720	4,670,916	2,013,960	15,668,389
2020	32,696,415	15,507,495	113,474,480	4,087,052	1,938,437	14,184,310

Additional research made possible by Virtual Laboratories

The on-line survey asked users the following question (or an equivalent variant) about how important the VL was to their research

> *If GVL had not existed, would you have been able to obtain the resources you last used from another source?*

For BCCVL, CVL and GVL the proportion of users who answered “No” to this question was 55.26%, 29.03% and 34.3% respectively. It is clear therefore that the VLs are important agents enabling research in their fields. Again by way of comparison, about 45% of EBI users also indicated that they could not have proceeded in their research without EBI.

If we assume that these percentages translate into research enabled by the VLs which would not otherwise occur, this implies that we can calculate the value of the research undertaken by VL users by multiplying the number of users by their annual average cost and applying the percentages quoted above. As with the previous section we present two results. The first users the cumulative number of users for the calculation and the second uses the number of new users. Tables 6.11 and 6.12 show the results. As with the value of research efficiency, this demonstrates that there are substantial benefits arising from the VLs in enabling research which would otherwise not have occurred, whichever method is used.

Table 6.11 Value of Virtual Laboratories in enabling additional research, using cumulative users, $

	Cumulative			Annual average		
	BCCVL	CVL	GVL	BCCVL	CVL	GVL
2013	0	6,520,762	3,781,977	0	6,520,762	3,781,977
2014	0	14,651,388	31,427,409	0	7,325,694	15,713,705
2015	8,860,592	26,034,265	55,290,864	2,953,531	8,678,088	18,430,288
2016	40,814,537	39,043,267	88,712,033	10,203,634	9,760,817	22,178,008
2017	104,722,428	53,353,169	137,220,003	20,944,486	10,670,634	27,444,001
2018	200,584,264	69,094,061	209,447,547	33,430,711	11,515,677	34,907,925
2019	296,446,101	86,409,042	305,661,872	42,349,443	12,344,149	43,665,982
2020	392,307,937	105,455,522	405,205,981	49,038,492	13,181,940	50,650,748

Table 6.12 Value of Virtual Laboratories in enabling additional research, using new users, $

	Cumulative			Annual average		
	BCCVL	CVL	GVL	BCCVL	CVL	GVL
2013	0	4,878,376	2,959,808	0	4,878,376	2,959,808
2014	0	8,130,626	27,645,432	0	4,065,313	13,822,716
2015	8,860,592	11,382,877	23,863,455	2,953,531	3,794,292	7,954,485
2016	31,953,945	13,009,002	33,421,169	7,988,486	3,252,250	8,355,292
2017	63,907,891	14,309,902	48,507,970	12,781,578	2,861,980	9,701,594
2018	95,861,836	15,740,892	72,227,545	15,976,973	2,623,482	12,037,924
2019	95,861,836	17,314,981	96,214,325	13,694,548	2,473,569	13,744,904
2020	95,861,836	19,046,480	99,544,109	11,982,730	2,380,810	12,443,014

Returns to research activities made possible by Virtual Laboratories

Because technology is important in the continuing development of new products and improved productivity, the role of research and development and its contribution to the economy has been studied widely. A review of these studies has been provided in Section 3 above which concluded that a 40% annual return on investment is a conservative estimate of the value of research.

Taking the value of the additional research due to the VLs from Table 6.12 we calculate the value of this research following the procedure set out by Beagrie and Houghton. We assume that the useful life of any research is 30 years and we depreciate the value at 3.4% a year so that the value in year 30 is zero. For each of the years 2013 to 2020 as shown in Table 6.12, we calculate the resulting benefits stream by applying this methodology. This will generate 8 benefits streams which we sum for each of the years 2017 to 2047. We then discount future benefit streams using a 3% discount rate and calculate a net present value (NPV) of the summed benefits streams. Finally we can express the NPV of these benefits as an annualised value by dividing by 30. Both the total NPV and the annualised value are shown for each VL in Table 6.13.

Table 6.13 Returns to additional research made possible by Virtual Laboratories $m.

	30 year benefit	Annualised benefit
BCCVL	2,277.8	75.9
CVL	609.5	20.3
GVL	2,356.0	78.5

7. Further assessment of the impact and value of the Characterisation Virtual Laboratory

Different Virtual Laboratories (VLs) share the same purpose, which is to facilitate data analysis, provide researchers with IT resources and promote collaborative research. Where the VLs differ is in their scope and implementation. A major point of difference for CVL is its method of operation because it works primarily with instrument facilities rather than end users. By developing data capture, analysis and visualisation workflows directly with instrument facilities, CVL aims to underpin the entire facility user community. This integration enables seamless transfer of data from the instruments for storage and analysis.

The CVL method of operation and ease of transfer means that users are not always aware that they are using CVL, and many consider the capabilities provided by CVL as a component of the instruments, rather than as a separate service. Low awareness of CVL among its users raises concerns about the representative nature of responses from the CVL user survey.

In collaboration with Dr Wojtek Goscinski, the manager of CVL, the current study used an additional approach to evaluate CVL from the perspective of managers from a number of imaging facilities. Imaging facilities house and maintain advanced imaging instruments, and they represent considerable national investment in Australia's research infrastructure. A list of imaging facilities that utilise CVL services is given in Appendix 2. To date, CVL has been integrated with 69 instruments in 26 imaging facilities.

The interviews conducted with facility managers provided a glimpse into diverse aspects of CVL value. Much of that value is additional to the direct benefit of CVL to individual users. The additional benefits included economies of scale, the potential for scaling up CVL application and the intrinsic value of CVL as a digital resource. These different types of value are outlined below.

(i) A centralised HPC capability cuts costs by reducing HPC replication across research organisations

Imaging instruments can generate vast amounts of data that requires extensive HPC capabilities for analysis. Dr Georg Ramm (Clive and Vera Ramaciotti Centre for Structural Cryo-Electron Microscopy, Monash University) manages an electron microscopy facility that contains many such instruments, most notably the Titan Krios cryo-electron microscope, which is used typically for 2D and 3D characterization of cellular or molecular structures and it is particularly data intensive. There are around 100 users at the centre, of whom approximately half rely on the HPC capability of CVL on MASSIVE for data storage, while the remainder require the analytical capacity of CVL for data processing.

Centralising HPC at the level of each imaging facility would be a cheaper alternative to user-funded HPC, though still considerably more expensive than the cost of maintaining CVL:

- A small computing cluster would cost around $200,000 and it would need to be updated within 5 years. Salary costs for part-time PhD-level staff to manage the cluster would add around $50,000 per year to the outlay, bringing the total to around $90,000 per year.

- Dr Andrew Janke (Centre for Advanced Imaging, University of Queensland) estimated CVL replacement cost at $250,000. The amount was based on the cost of setting up an in-house platform for the centre.

- Prof Sampson (Centre for Microscopy, Characterisation and Analysis, UWA) estimated that when implemented at full capacity, the value of CVL services to the centre could well be worth $50,000 per year. At this stage, flow and mass cytometer is the only instrument integrated with CVL, although integration with other instruments is being rolled out.

- Dr Ian Harper from Monash Micro Imaging (MMI) estimated the cost of replacing the access to HPC through CVL at $20,000 per year.

Using Dr Harper's most conservative estimate, it would cost over $500,000 per year to replace HPC services currently provided by CVL to 26 facilities. This figure is well above the CVL running cost of $177,000-$320,000 per year (Table 2.2). The estimated replacement cost is for HPC alone; it does not take into account the value of all other services provided by CVL, which are outlined below.

(ii) Potential for scaling up the CVL platform

CVL has been adopted widely in a relatively short time. In less than four years since its inception, it has been integrated with 69 instruments across 26 imaging facilities. The expansion of CVL is ongoing. In addition, CVL integration with commonly used technology has the potential for scaling up. For example, the integration of the flow cytometer at the Centre for Microscopy, Characterisation and Analysis in UWA, is expected to be replicated widely. Flow cytometry is increasingly used for cell counting and sorting not only in research, but also in major hospitals. There are over 20 machines and around 100 users of flow cytometry in WA, over 100 machines in Australia and around 5,000 worldwide. Integration with CVL has the potential to be replicated in other centres, attracting more users to the platform.

Light microscopy is another well established and common technology. Dr Ian Harper from Monash Micro Imaging (MMI), outlined plans to integrate MMI instruments with CVL. MMI is a light microscopy facility that contains instruments valued at around $50million, and which attract approximately 500 users. MMI is located on three campuses: Monash University (Clayton), Alfred Hospital and Monash Medical Centre. At this stage only the instruments at the Clayton campus are integrated with CVL. Within the coming year, 40-48 MMI microscopes at all three campuses are expected to be integrated with CVL.

(iii) Increasing the efficiency of research and the impact of research investment

In providing access to secure storage for experimental data, CVL contributes to improved research outcomes. Dr Ian Harper from Monash Micro Imaging (MMI) described problems with data loss prior to integration with CVL, when USB data transfer was used. Dr Ramm (Centre for Structural Cryo-Electron Microscopy) also recalled prolonged periods of downtime when users brought their own hard drives to download data, making instruments vulnerable to attack by computer viruses.

The ability to store all experimental data securely allows researchers to interrogate old data in subsequent years to answer new research questions. The ability to share data with collaborators through the CVL platform also means that the same data can be interrogated by other researchers. Reusing experimental data in this way and improves the efficiency and impact of each experiment; it also reduces the need to repeat experiments

Increasing reproducibility of research findings is another way to improve the efficiency and impact of experimental research. Dr Andrew Janke (Centre for Advanced Imaging, UQ) emphasised that one of the main benefits of CVL to his facility is that it facilitates reproducibility. Dr Janke used the example of “quarantining” superseded versions of analytical software, such as FSL, a package of image analysis tools used for MRI brain imaging data. After a release of updated FSL older versions are no longer available. This often means that results of earlier experiments cannot be replicated. A recent study estimated that fewer than 16% of neuroimaging results are reproducible (Russell et al 2017). CVL preserves all releases of the software.

Dr Ceguerra (Australian Centre for Microscopy & Microanalysis, University of Sydney) noted that in the absence of CVL, the return on the $5 million investment in the Atom Probe would be greatly diminished in terms of research outcomes. The Atom Probe enables 3D imaging and chemical composition measurement. Because of the novelty of this technology, there are few analytical tools available and users are required to develop their own methods and software. The Atom Probe workbench developed by CVL acts as a repository of analytical software that is developed by users. This repository represents a significant investment in research time – over 14 years of effort from multiple people. According to Dr Ceguerra, without CVL some projects would be set back by as much as five years, with the researchers having to develop the tools they need by themselves. CVL is also critical for disseminating research outcomes in the Atom Probe research community.

(iv) Value of CVL as a digital resource

Another important aspect of the value of CVL is the development of its intrinsic worth as a digital resource is. Dr Ceguerra emphasised the importance of CVL as a resource for the small community of community of researchers working with the Atom Probe. There are close to one hundred such instruments worldwide[2] with around 500-600 researchers trained to use them, 34 of them at the facility in Sydney. Despite its small size, this community represent an important field of research that has produced far-reaching discoveries in materials engineering.

As already mentioned, the atom probe is novel technology without a canon of well-established analytical methods. It has fallen to users to develop the methods they need. The repository of user-generated software on the CVL Atom Probe workbench has no equivalent and has become the key platform for Atom Probe research worldwide. CVL is also critical for disseminating research outcomes in the Atom Probe research community. The valuation of the intrinsic value of VLs as a digital resource is outlined in more detail in Section 8 of this report.

Dr Andre Janke said that CVL provided novice users with an easy to navigate mechanism for to rapidly get up to speed with their analysis without the need to install or configure software, something that previously took a large investment of time. Dr Janke estimated the saving in time as approximately three months. That time is valued at over $19,000 junior for a postdoctoral fellow (commencement level Academic level A salary is $77,819, Table 6.1) or $6,670 for a PhD student (Monash University PhD annual stipends are $26,682)

Interviews with imaging facilities managers provided an insight into far-reaching benefits of CVL, which would not be apparent from survey responses of individual users. The categories of value identified in this way would be equally applicable to the other VLs. In a similar way, BCCVL, GVL and HuNI offer economies of scale through centralising IT resources; and aim to develop value as digital resources, to improve the efficiency and impact of research and to expand their services outside the host organisations and outside

[2] Atom Probe facilities around the world (http://www.atomprobe.com/2ndLinks/apt-internet-sites.aspx

8. Qualitative valuation of Nectar Virtual Laboratories

The impact and value of Nectar VLs calculated in the Section 6 are necessarily restricted to those for which the key inputs to the calculation can be readily quantified and expressed in economic terms.

It is clear however that the activities of VLs extend well beyond this into areas which are more difficult to quantify. We attempt to capture some of the qualitative benefits of Nectar VLs using the Balanced Value Impact Model framework suggested by Tanner (2012). Table 8.1 provides a brief description of these types of value. Table 8.2 at the end of this section summarises important aspects of the values described in Table 8.1 for BCCVL, CVL and GVL.

Table 8.1 Types of value in Balanced Value Impact framework

Type of Value	Definition
Utility Value	People value the utility afforded through use of the digital resources now or sometime in the future.
Existence and/or Prestige Value	People derive value and benefit from knowing that a digital resource is cherished by persons living inside and outside their community. This value exists whether the resource is personally used or not.
Education Value	People are aware that digital resources contribute to their own or to other people's sense of culture, education, knowledge and heritage and therefore value it.
Community Value	People benefit from the experience of being part of a community that is afforded by the digital resource.
Inheritance / Bequest Value	People derive benefit from the inheritance passed down to them and satisfaction from the fact that their descendants and other members of the community will in the future be able to enjoy a digital resource if they so choose.

Based on Tanner (2012) p 37

Utility value

The preceding section has shown the value that users put on VL services to the extent that this can be expressed in economic terms.

In the on-line surveys users were asked the following question

To what extent do you benefit from using VL in any of the following ways?

Haven't used, No benefit, Low benefit, Medium benefit, High benefit, Very high benefit

Table 8.2 Extent of benefits from Virtual Laboratories, % of respondents

Services	BCCVL		CVL		GVL	
	Medium and higher	High and very high	Medium and higher	High and very high	Medium and higher	High and very high
Data & tools	73.8	57.4	72.5	70.0	60.6	44.8
Collaborations	23.0	11.5	50.0	30.0	48.7	25.0
Training	37.7	27.9	27.5	15.0	51.2	32.9
User support	27.9	19.7	---	---	36.8	29.0
Other	27.9	19.7	7.5%	2.5%	36.8	29.0

In the on-line surveys users were asked the following question

What impact would it have on your work or study if you could not access VL services and resources?

No impact, Slight impact, Moderate impact, Major impact, Severe impact

For BCCVL users 18.2% answered that if they could not access the services and resources provided by the VL this would have a major or severe impact. For CVL and GVL the percentages were higher at 52.8% and 35.7% respectively (Table 8.3).

However taking moderate, major and severe impact as significant, the percentages of respondents were 41.8%, 75.0% and 72.9%.

Table 8.3 Impact if could not access Virtual Laboratory services, %

	BCCVL	CVL	GVL
No impact	23.6	5.6	11.4
Slight impact	34.5	19.4	15.7
Moderate impact	23.6	22.2	37.1
Major impact	12.7	27.8	27.1
Severe impact	5.5	25.0	8.6
Major and severe impact	18.2	52.8	35.7
Moderate, major and severe impact	41.8	75.0	72.9

CVL

We conducted phone interviews with the managers of a number of imaging facilities that have worked closely with CVL on integrating their facilities with the on-line storage and computing facilities offered through CVL.

They provided the following descriptions of the value of CVL to their facilities.

> ***Dr Keith Schulze, Image Analyst, Monash Micro Imaging, Monash University***
>
> *MyData and Store.Monash represent a significant advance in data handling at Monash Micro Imaging. Transfer and storage of user data is now reliable, seamless and secure. Store.Monash provides users with the ability to share data with colleagues and collaborators in a convenient and secure manner. It also has mechanisms to capture and expose important metadata that allow for better reuse and reproducibility of data.*
>
> *Next-generation imaging technologies, like the Lattice light-sheet microscope, are capable of producing data at a rate of Terabytes per hour. The tools for automated handling and storage of data provided by CVL are a key enabler for researchers to derive the most benefit from these large datasets i.e., they spend less time struggling with data transfers and more time extracting interesting information from their data. Moreover, CVL and Nectar provide a crucial platform on which tools to analyse and visual this data can be developed and deployed.*
>
> ***Dr Andrew Mehnert, Group Leader – Data Management, Analysis and Visualisation, Centre for Microscopy Characterisation and Analysis, The University of Western Australia***
>
> *The Centre for Microscopy, Characterisation and Analysis (CMCA) is a University facility that collaborates in microscopy and characterisation, supporting research excellence locally, nationally, and internationally. It comprises ~40 staff, more than 500 users and hosts ~50 instrument platforms across cytometry, optical microscopy, micro-magnetic resonance imaging (microMRI), preclinical bioimaging, electron microscopy (EM), X-ray micro-computed tomography (microCT), secondary ion mass spectrometry, bio-organic mass spectrometry, X-ray diffraction and nuclear magnetic resonance (NMR) spectroscopy. The CMCA collaborates in and supports research across biological science, biomedical science, earth science and physical science.*
>
> *CMCA users are acquiring ever-larger multi-dimensional data sets and are increasingly using multiple instrument platforms; e.g. microCT together with EM and Raman spectroscopy. This presents a Big Data challenge, not only in terms of managing/curating this data over the research life cycle, but also in terms of*

analysing this data to facilitate new discoveries. To solve this challenge the CMCA is leveraging the Characterisation Virtual Laboratory (CVL) and CVL-supported services including MyTardis. Over the last 12 months the CMCA has been working with Monash University to develop the Cytometry workbench (collection of software tools) for the CVL to support the analysis of data from image-, mass- and flow-cytometry instruments. The CMCA has also integrated several EM instruments with MyTardis and is in the process of integrating its NIF flagship MRI scanner. The CMCA plans to integrate all of its instruments with MyTardis and to develop additional workbenches and workflows in the CVL in support of its users/researchers. The CVL and supported services represent the only viable solution across multiple instrument platforms and modalities. Moreover, looking to the future, the CVL offers a solution to the analysis and visualisation of very large data sets using tools and compute resources not otherwise available from a desktop workstation.

Dr Andrew Janke, Informatics Fellow, National Imaging Facility, University of Queensland

The value of CVL and managed workbenches in neuroimaging and preclinical imaging to the National Imaging Facility (NIF) is predominately around encouraging our users to perform reproducible science. CVL provides a tool in which researchers can process and analyse their imaging data safe in the knowledge that if they need to reproduce the analysis in 5 years' time the same versions of software will still be available.

Traditionally this has not been the case in imaging research and software packages and operating systems are a moving target. CVL provides a mechanism to freeze in time a particular analysis pipeline. In addition CVL provides NIF with an easy to navigate mechanism for novice users to rapidly get up to speed with their analysis without the need to install or configure software, something that previously took a large investment of NIF personnel time.

Education value

In the on-line surveys BCCVL and GVL users were asked the following question

How did you learn to use the services provided by the VL?

As shown in the table below, 53.8% of BCCVL users, 50.0% of GVL users rely on the respective VLs to learn the analytical tools required for data analysis in their respective fields.

As is evident from Table 8.4, an important aspect of both BCCVL and GVL is the training they provide to researchers and students.

Table 8.4 Training provided by Virtual Laboratories, % of respondents

	BCCVL	GVL
Already proficient	11.5	21.1
Tutorial through the VL website	21.3	18.4
Face-to-face course provided by VL personnel	32.8	9.2
Face-to-face course provided by someone else	0.0	22.4
Another way	16.4	15.8
Missing	18.0	13.2
Total	100.0	100.0

One of the important benefits of GVL is to provide to users the resources they need which otherwise would require advice from experienced bio-informaticians. The supply of trained bio-informaticians is a critical bottleneck in expanding research within the field of genomics, so enabling researchers to bypass this bottleneck is an important contribution that GVL makes.

Over the period to February 2017, GVL has undertaken training courses for 313 users, who give an average rating of 4.5 out of 5 for these courses.

Benefits to users

BCCVL

In its Snapshot for 2016, BCCVL (2016) provides the following quotes from users.

> *...because it provides an environment for experimenting with models, and also keeps careful track of these experiments, BCCVL also encourages best practice and transparency in modelling.*
>
> *With its easy to use interface, accessible from anywhere, it opens the field to a whole new array of researchers who understand the systems they are working on, but do not have the technical skill-sets or hardware to properly answer their questions.*
>
> *… essentially the BCCVL has enabled us to ask questions that we couldn't ask before – questions we may have wanted to ask but couldn't logistically hope to answer, so it's opened up a whole new field of enquiry.*

CVL

In its annual report for 2015-16, the Massive project at Monash University noted that

> *CVL has underpinned workflow deployment at two Australian Synchrotron beamlines for access to the MASSIVE Desktop. Researchers visiting both the Imaging and Medical Beamline (IMBL) and the X-ray Fluorescence Microscopy (XFM) beamline are automatically created a beamline visit project, and user accounts. Authentication is*

integrated with Australian Synchrotron so that users can use their AS credentials to log into the system. A set of beamline change over scripts, developed in collaboration with Australian Synchrotron, control the flow of data. The impact of this work is significant. Researchers are provided with access to a remote desktop environment for the duration of their beamline visit that provides access to the data captured, and tools for data processing and visualisation

Additionally, CVL software is now being adopted by two major international supercomputing centres:

> Julich Supercomputing Centre, is in the process of deploying Strudel to support visualisation users and high-end commercial engineering applications;

> Edinburgh Parallel Computing Centre for industry access to HPC systems under the EU FP7 project, Fortissimo.

With CVL Nectar funding, Monash University is developing an instrument integration app, called MyData to make integration quicker, simpler and less reliant on specialist IT support. As a result of this project MyData is now used at 35 instruments, across 10 facilities, at 4 institutions, in addition 17 further instruments are planned at 4 institutions. In addition, this project has made MyTardis easier to use for Facility Managers. (p23)

HuNI

Descriptions by two HuNI users of its value, which includes new approaches to multi-disciplinary research and connecting with other researchers. 'Users can capture relationships between content, build pathways and structures, and share and distribute data. It provides a platform where serendipitous collaborative opportunities can quickly emerge' (User 2).

User 1 (literary studies)

I work in the area of literary studies, particularly literary and cultural history in the nineteenth century, and my research cuts across a range a physical archives and libraries around the world. While I use a number of digital tools in my research (particularly as digitisation has opened up a swathe of historic printed texts), HuNI opened up my thinking and approaches to research in ways that these individual tools had never encouraged. In particular, HuNI innately encourages users to identify the interdisciplinary connections within their research field. As our research methods have largely been shaped within our disciplinary silos, I was not even aware of some of the datasets that HuNI draws on but which proved to be supremely useful to my research project. Moreover, HuNI represents a real step forward in efficiency in that simple awareness of these other datasets on their own would still mean increased labour in *individually locating and searching them. Perhaps most exciting and unexpected of all was the ability of HuNI to connect my ideas and research with the work of other researchers through its visualisation capabilities. These kinds of associations in relation to specific research sites (particular plays, books, or public figures, for example) are simply not possible in any other forum apart from the random networks we form as academics. In this respect, HuNI clearly has the potential to radically transform how we conduct our research in relation to—and potentially in tandem with—other scholars and members of the public.*

User 2 (Archivist)

HuNI (Humanities Networked Infrastructure) makes a significant and valuable contribution to Australia's information infrastructure. In bringing together 30 curated, authoritative and scholarly datasets in a well-designed online resource, HuNI supports diverse research and provides researchers with diverse content without the noise of large aggregators. Through this, HuNI also helps increase the visibility and use of these 30 foundational humanities resources which together constitute a substantial investment of resources and scholarship spanning more than two decades.

More importantly, unlike aggregators and 'portals', HuNI brings this content into a research platform which supports the type of relational, non-hierarchical, iterative engagement with collections and data that is central to contemporary humanities practice. Users can capture relationships between content, build pathways and structures, and share and distribute data. Through this, HuNI not only fosters serendipitous discovery, it provides a platform where serendipitous collaborative opportunities can quickly emerge in an online environment. As the user base grows, this aspect is increasingly likely to spark broader collaborative work by humanities researchers, contributing to the strength and diversity of the sector as a whole.

Table 8.5 Summary of benefits provided by BCCVL, CVL and GVL using Balanced Value Impact framework

Value drivers and indicators	BCCVL	CVL	GVL
1. Utility Value			
• **Reported benefit from access to data and tools** [1]			
of benefit (number of respondents)	45 (73.8%)	29 (72.5%)	46 (60.6%)
of high benefit (number of respondents)	35 (57.4%)	28 (70.0%)	34 (44.8%)
2. Existence and/or Prestige Value			
• **reach across different organisations [e-mail suffixes]** [2]			
Number of Universities	70 (46.7%)	46 (49.5%)	24 (64.9%)
Number of Research/ Not-for-profit organisations	20 (13.3%)	33 (35.5%)	8 (21.6%)
Number of Government agencies/departments	38 (25.3%)	7 (7.5%)	--
Number of Companies	22 (14.7%)	7 (7.5%)	4 (10.8%)
• **Reach outside Australia** [2]			
Number of countries (including Australia)	20	15	1
Australia (number of users)	1005 (94.8%)	2,388 (93.4%)	665
Other countries (number of users)	55 (5.2%)	170 (6.6%)	None
• **recognition by providers of other digital platforms**	See text	See text	See text
3. Education Value			
• **training trough courses by VL personnel/ VL website**	33 (54.1%)	--	21 (27.6%)
• **VL training**			
of benefit (number of respondents)	23 (37.7%)	11 (27.5%)	39 (51.2%)
of high benefit (number of respondents)	17 (27.9%)	6 (15.0%)	25 (32.9%)
• **satisfaction surveys for GVL courses (mean score out of 5)**	--	--	4.5
4. Community Value			
• **use of VL platforms for collaboration**			
of benefit (number of respondents)	14 (23.0%)	20 (50.0%)	37 (48.7%)
of high benefit (number of respondents)	7 (11.5%)	12 (30.0%)	19 (25.0%)
• **user support**			
of benefit (number of respondents)	17 (27.9%)	--	28 (36.8%)
of high benefit (number of respondents)	12 (19.7%)	--	22 (29.0%)
5. Inheritance / Bequest Value			
• **VL users upload new datasets to a VL (number of respondents)**	14 (22.9%)	--	22 (29.0%)
• **Number of datasets uploaded by Dec 2016**	--	35,787	--
• **Repository of user-written algorithms**	--	yes [5]	yes

[1] Survey of VL users
[2] Information derived from user e-mail suffixes
[3] Student feedback from participants in 31 GVL training course (information provided by VL

9. Summary and conclusions

The Nectar funding for three VLs examined in this study has had demonstrable benefits, when measured in both quantitative and qualitative terms. For an expected expenditure by Nectar and partners of around $4.4 to $7.0 million to the year 2020 (or around $550,000 to $870,000 in annual terms) the three VLs have generated economic value exceeding this.

Table 9.1 summarises the calculation of economic benefits expressed in annual terms and compares this to the annualised cost of each VL.

Table 9.1 Summary of economic benefits and costs for Virtual Laboratories

	Annualised benefit,$	Annualised cost, $	Ratio
Contingent valuation			
Willingness to pay			
BCCVL	2,324,397	550,754	4.2
CVL	1,235,410	612,356	2.0
GVL	1,901,364	869,479	2.2
Willingness to accept			
BCCVL	20,142,090	550,754	36.6
CVL	11,454,271	612,356	18.7
GVL	4,031,769	869,479	4.6
Efficiency impacts			
BCCVL	4,087,052	550,754	7.4
CVL	1,938,437	612,356	3.2
GVL	14,184,310	869,479	16.3
Additional research impact			
BCCVL	11,982,730	550,754	21.8
CVL	2,380,810	612,356	3.9
GVL	12,443,014	869,479	14.3
Returns to additional research			
BCCVL	75,925,851	550,754	137.9
CVL	20,318,154	612,356	33.2
GVL	78,532,855	869,479	90.3

The ratios for all VLs are higher than one indicating that they all generate benefits in excess of their costs. For BCCVL and GVL the ratios are consistently high across all measures of value and are higher than those often achieved by conventional physical infrastructure. The study indicates that the VLs contribute value in different ways. For instance, the efficiency impact ratio for GVL is higher than that for BCCVL, the contingent valuation ratio and the additional research ratio are higher for BCCVL than for GVL. These variations reflect differences in the way in which the VLs deliver value to their users.

Taking a wider perspective on both quantitative and qualitative benefits, it is clear from the case study of CVL that it has generated considerable benefits for the imaging facilities with which it works. These facilities would otherwise incur considerable costs (discussed in Section 7 but not fully captured by the study) in replicating the services they provide. The facility managers have also provided evidence of the wider benefits of working with CVL. We have used the Balanced Value Impact framework to describe characteristics of VLs that provided a range of benefits to users and communities. This approach could be adapted further for providing insight into the value and impact of other VLs.

We noted in the Introduction that most VLs funded by Nectar have only been active for a few years and are still in their growth stages. An evaluation of their overall impact and value might best be done from the perspective of some years in the future when the VLs are in a more mature growth phase. Therefore the analysis and conclusions drawn in this study should be treated as preliminary and depend significantly on the assumptions made about future growth paths.

Although VLs share many features in common, they differ significantly from each other in terms of the services they provided to their target communities. This means that the approach to the evaluation of value and impact must be tailored to the circumstances of each one and that considerable effort should be made in understanding the services provided by each VL and how these services are delivered to and benefit their target communities.

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Appendix 1 Virtual Laboratories funded by Nectar

Name
All-Sky Virtual Observatory
Alveo
Biodiversity and Climate Change Virtual Laboratory
Characterisation Virtual Laboratory
Climate and Weather Science Laboratory
Endocrine Genomics Virtual Laboratory
Microbial Genomics Virtual Laboratory
Genomics Virtual Laboratory
Humanities Networked Infrastructure
Industrial Ecology Virtual Laboratory
Marine Virtual Laboratory
Virtual GeoChemistry Laboratory
Virtual Geophysics Laboratory
Virtual Hazard Impact and Risk Laboratory

Appendix 2 CVL imaging facility partners

Imaging facility
Animal MRI Facility, Florey Neuroscience Institutes
Australian Centre for Microscopy & Microanalysis, USydney
Australian Synchrotron
Biological Optical Microscope Platform (MDHS), UoM
Biological Resources Imaging Laboratory, UNSW
Australian Centre for Neutron Scattering, ANSTO
Centre for Advanced Imaging, UQ
Centre for Microscopy and Microanalysis, UQ
Centre for Microscopy, Characterisation and Analysis, UWA
Florey, Melbourne Brain Centre
FlowCore, Monash University
Melbourne Brain Centre Imaging Unit, UoM
MicroNano Research Facility, RMIT
Monash Biomedical Imaging
Monash Biomedical Proteomics Facility
Monash Injury Research Institute
Monash Micro Imaging
Monash Micro Imaging (AMREP)
University of Newcastle, Light Sheet Microscopy
Queensland Brain Institute
Single Molecule Science, UNSW
Royal Children's Hospital
Royal Melbourne Hospital

St Vincents Hospital
The Clive and Vera Ramaciotti Centre for Structural Cryo-Electron Microscopy
X-ray Microscopy Facility for Imaging Geo-materials (XMFIG), Monash