Researchers in the cloud

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Over the past 5 years, tens of startups have emerged promising to revolutionize the way science is conducted. Often founded by young researchers after realizing the lack of digital tools for researchers, these startups bring new tools to conduct experiments, manage laboratories, or explore the literature. Many of these tools use so-called cloud technologies, developed in the early 2000s to make complex software cheaply, rapidly, and easily accessible through the user's web browsers. The technology owes its popularity to its strong technical advantages, which in-clude scalability, automatic software updates, easy porta-bility to mobile devices, and high reliability. Now applied to the needs of the research community, cloud-based services are starting to change the way research is conducted, by better connecting researchers, creating new and more-open communities, and introducing mobility to research.

Cloud-based services to connect researchers

Research has never been so dependent on collaboration and communication. Large amounts of information need to be easily and rapidly exchanged at all stages of research projects. Emails are limited in the size of the files that can be attached and cannot properly organize or display large amounts of information. The research management tool Labguru (Table 1) is a browser-based service that allows researchers to plan experiments, write protocols, and record results in a digital laboratory notebook. The data is stored in the cloud, making it easy to share with colleagues and collaborators. A multitude of other cloud-based services connect researchers within larger scientific communities. Social-media platforms such as ResearchGate, Academia, MyScienceWork, and LabRoots are designed to share papers and experimental tips and tricks and to stimulate collaborations (Table 1). More specialized platforms also exist: Addgene and PlasmID to share and deposit information about plasmids; Protocols.io to share protocols; GitHub and Bitbucket to share code; SlideShare to share presentation slides; and FigShare to share figures, in particular unpublished results (Table 1). These services host, organize, and make large sets of data searchable and accessible to all, at virtually no cost for the users. The successes of Research-Gate (4 million users), Addgene (over 30 000 shared plasmids), and FigShare (over 1 million shared files), among others, are signs of a real need for such services and should encourage others to follow (Figure 1).

Real-time collaborative writing has also been made possible by cloud-based tools. Cloud-based word processors such as Google Docs, Office Online, and SciGit allow live text editing by multiple users and offer advanced version control (Table 1). Enriched by numerous plugins, Google Docs has become a serious rival to traditional word pro-cessors. The Paperpile plugin, for example, is a browser-based reference manager integrated into the Google Drive suite of applications (Table 1). Users can directly add references to the manager while browsing databases such as PubMed (http://www.ncbi.nlm.nih.gov/pubmed) or Goo-gle Scholar (http://scholar.google.com). The references and full texts are then stored on the Google Drive cloud storage. For those that prefer writing in LaTeX, online collabora-tive writing is possible with ShareLaTeX, WriteLaTeX, and Authorea, which offer visually pleasing, browser-based solutions (Table 1).

Cloud-based services bring mobility to research

Whether at the bench or on the field, new services allow researchers to record their observations, results, and protocols on mobile devices. Cloud technologies are changing the standards for electronic notebooks, bringing trans-platform compatibility, mobility and security of storage. LabArchives, Hivebench, SparkLix, Labfolder, and CellKulture are among numerous electronic laboratory notebooks that can be used both on the computer and on a mobile device at the bench (Table 1). Every detail of an experiment can be recorded on the spot and stored in the cloud to be processed later at the desk, avoiding data-entry errors. ZappyLab and Shazino are two young startups specialized in the development of mobile applications for researchers. Simple but useful applications such as labora-tory counters only recently became a reality. ZappyLab also launched PubChase, a literature-search and -suggestion tool (Table 1), and Protocols (http://protocols.io), a centralized and open-protocol repository accessible on mobile devices. There is even mention of supporting Google Glasses so that users can follow or record protocols at the bench.

Cloud-based services open new possibilities

By sharing the cost of expensive infrastructure between thousands of users, cloud computing could also open new possibilities for researchers, especially for the lesser funded. Services such as RunMyCode allow researchers to upload code that can then be run on their servers (Table 1). This comes as a complement to publication and allows authors to showcase their code and everyone else to access the latest scientific methods freely and rapidly. A cheap alternative to graphing software such as SigmaPlot and Origin is Plotly (Table 1). The free browser-based data-analysis and graphing tool allows users to graph plots, fit data, and perform statistical analysis. Plotly is also changing how data are communicated by replacing the still images of graphs and plots with dynamic figures from which the data can be easily extracted. Another example is Benchling, which offers a wide range of bioinformatic tools at no cost for

Table 1. Cloud-based tools for research

Connecting researchers		
Academia	LinkedIn for researchers	http://www.academia.edu
Addgene	Share and order plasmids	http://www.addgene.org
Bitbucket	Share code	https://bitbucket.org
FigShare	Share files and figures	http://figshare.com
GitHub	Share and collaborate to write code	https://github.com
LabRoots	Research social network	http://labroots.com
MyScienceWork	Research social network available in eight languages	https://mysciencework.com
PlasmID	Harvard's plasmid-sharing platform	http://plasmid.med.harvard.edu
Protocols.io	Share scientific protocols	http://www.protocols.io
ResearchGate	Research social network with over 3 million registered users	http://www.researchgate.com
SlideShare	Share presentation slides	http://www.slideshare.net
Collaborative writing		
Authorea	Web-based LaTeX collaborative writing	https://www.authorea.com
Google Docs	Google's online word processor	https://docs.google.com
Office Online	Microsoft's online word processor	https://office.com
Paperpile	Reference manager for Google Docs	https://paperpile.com
PubChase	Literature search on the go	https://www.pubchase.com
SciGit	Collaborative writing tool for researchers	https://www.scigit.com
ShareLaTeX	Web-based LaTeX collaborative writing	http://www.sharelatex.com
WriteLaTeX	Web-based LaTeX collaborative writing	http://www.writelatex.com
Cloud-based electronic laboratory notebooks		
CellKulture	Laboratory notebook for cell culture	http://cellkulture.com
Hivebench	Includes inventory and protocol management	http://www.hivebench.com
LabArchives	Connected with Prism scientific-graphing software	http://labarchives.com
Labfolder	Simple and effective laboratory notebook	https://www.labfolder.com
Labguru	All-in-one solution for research groups	http://www.labguru.com
Docollab	Includes protocol management	http://www.docollab.com
Other cloud-based tools		
Benchling	Web-based suite of bioinformatic tools	https://benchling.com
Plotly	Web-based plotting software	https://plot.ly
RunMyCode	Share and run code on the cloud	http://www.runmycode.org

academic researchers (Table 1). The web-based interface and the centralization of all essential bioinformatic tools on one platform allow users to easily store, organize, and share their bioinformatic data.

A few challenges ahead

Although the promises of these new tools are great, their development faces numerous challenges. First, efforts to inform about the existence of these new tools and educate about their usefulness are needed. Funders and research centers should be more informed in this regard and help their researchers with the transition. The change in habits and increase in user adoption will come with time and with the consolidation of the industry, which will lead to fewer but more trustworthy services. On the financial side, although some are currently free, many services charge a monthly fee. This pay-for-use model can add up to a significant cost for less fortunate laboratories. Services like FigShare and Labguru offer institutional licenses to lower cost and help set a standard within organizations. Standards that would apply throughout the industry are not yet here, but the association of complementary tools has already begun, with the Labfolder integration of FigShare and Paperpile working as a plugin for Google Docs.

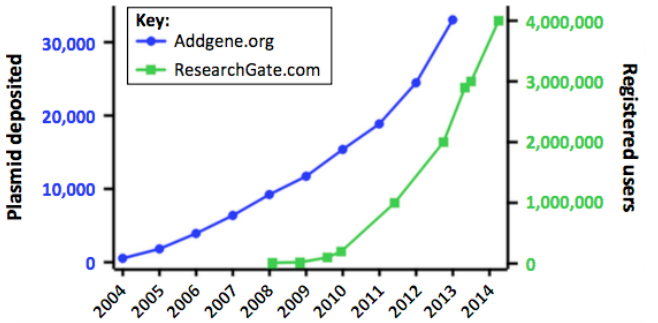

Figure 1. The growing success of Addgene and Researchagte. Sources: Melina Fan, Addgene (http://www.addgene.org) and the ResearchGate blog (https://news.researchgate.net).

Bright future on the horizon for digital science

Regardless of the challenges, the future seems to be bright for the digital-science space. The tools described here answer clear needs of the research communities and young researchers are increasingly using them in their everyday work. Larger companies such as Digital Science are taking the lead in promoting these new services. Digital Science's mother company, Nature Publishing Group, organizes the annual SpotOn conferences, where digital tools for re-search are presented and discussed. Changes in science policy suggest that governmental research agencies have also identified digital science as a priority. In this regard, the European Commission has formalized a digital-science policy for their multi-billion dollar Horizon 2020

research program. Governments and funding agencies are also increasingly requesting ways to track spending in detail and to manage the data generated, making such tools invaluable to conduct research in the 21st century. Finally, a growing digital-science community has formed around social networks and blogs. This com-munity will be useful to help users choose from an ever-increasing collection of tools. Over 100 online tools for researchers are now listed on the Connected Researchers blog (http://connectedresearchers.com), and counting.