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Commentary

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Moving Chemical Education into the Cloud(s)

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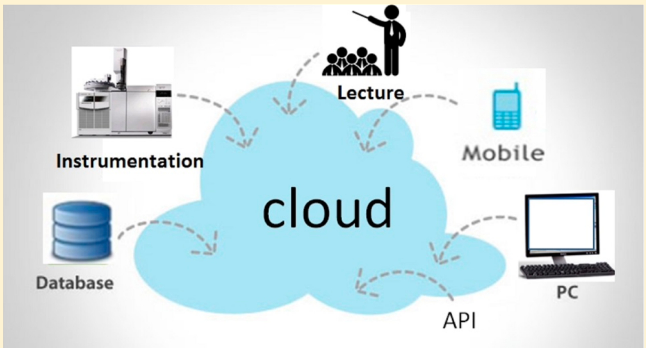
ABSTRACT: Many U.S. colleges and universities are adopting cloud computing, which may be defined as a distributed computing system that provides access to virtual resources, including computer hardware, networks, software, development platforms, and memory, at an off-site location and that can be accessed locally. Thus, far, this development has been driven primarily by the hope for administrative benefits, but the cloud also presents some excellent opportunities for chemical educators. Moving to the cloud can allow every student in a class to have access to all of the resources necessary for the class, simply by accepting an invitation to join a site. This encourages collaboration and the development of new educational models.



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■ INTRODUCTION

A recent *Educause Review* article has noted, "Institutions of higher learning are moving their operations to the cloud at a rapid pace."[1] This trend, commonly called cloud computing, has often been initiated by migration of campus electronic mail to off-campus servers, such as Google Mail. Even at the K−12 level, the use of the cloud is rapidly increasing. According to a recent survey of 400 K−12 IT professionals by the CDW company, a provider of hardware and software, these schools delivered 67% of their IT solutions fully or partially through the cloud in 2015, compared with 42% in 2014.[2] Although colleges and universities have been slower to adopt cloud computing than other businesses, the apparent financial savings are pushing more institutions of higher education in this direction. Cloud computing may have many advantages for a campus as a whole; this leads to the question of whether or not chemical educators might find these new capacities to be beneficial in their classrooms.

■ WHAT IS CLOUD COMPUTING?

Sultan has written a useful overview of cloud computing in education in which he proposes defining cloud computing as "clusters of distributed computers (usually large data centers and server farms) which provide on-demand resources and services over a networked medium (usually the Internet)", and this discussion will use his definition.[3] Although the term "cloud computing" may be relatively new, the idea of using essential computing services located on servers that are off site is already commonplace. Some examples of this would include Google search, Facebook, Wikipedia, Hotmail, and YouTube. For chemists, the classic example of a cloud service is, of course, *Chemical Abstracts*, and most campuses have moved their journal subscriptions from hardcopy to off-campus servers accessed through the Internet.

There are a large number of commercial vendors who are competing to provide cloud services; Wikipedia lists over 200 web pages classified as cloud computing providers and notes that this "may not reflect recent changes."[4] These vendors range in size from major players, like Microsoft, Google, and Amazon, to smaller but popular companies, like Dropbox and Box. Many colleges not only have moved their electronic mail to off-campus servers, like Gmail, but also are expanding the shift to include campus software, personnel files, student advisement, data analytics, and learning management systems.

■ USING THE CLOUD TO TEACH CHEMISTRY

Perhaps the simplest way to use the cloud for teaching in an undergraduate course is to employ one of the commercial services that saves files on an offsite computer. Thus far, chemical educators have been most likely to use software like Dropbox or Google Docs to collect and share data, because these programs are free and readily available. Flipped classrooms and massive open online courses (MOOCs) require the students to retrieve information from a central server. Thus, these teaching models are both dependent upon some form of cloud services to provide student access. These types of interactions may become easier as more campuses adopt Microsoft 365 (MS 365), which makes the software suite from Microsoft Office available from the cloud, including the cloud service called OneNote.

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Cloud software can be quite useful in laboratories, since it almost totally eliminates the need for paper reports and opens new possibilities for student collaboration. The idea of networking chemistry lab equipment is over a decade old, but in the past it has been done with physical connections rather than with the cloud.[5] More recently, Weibel has networked a physical chemistry laboratory using Google Drive;[6] Amick has also done this in an organic laboratory by using the Notability software on iPads,[7] and Bennett and Pence have used Google Docs to collect student results from undergraduate organic laboratories.[8] In each case, the students upload their results to cloud software; the professor accesses and grades it from his or her computer. Then, the instructor's comments are returned to the student via the cloud. Soulsby has configured NMR spectrometer software so that data can be uploaded from the instrument to a Google Group for each laboratory section. Students can analyze their data on any connected computer, which frees up the NMR instrument so that each group does not have to wait for a previous group to finish working with their data.[9]

■ COOPERATIVE LEARNING IN THE CLOUD

Denton argues that cloud computing provides opportunities for students to share work and ideas and encourages the interdependence that is characteristic of cooperative work.[10] The cloud facilitates group brainstorming sessions, and often includes functions, such as the command *See revision history* in Google Documents, to keep track of past revisions, including when the revision was made and by whom. Having access to the past comments helps students and teachers reflect on how the discussion has developed and what contributions each individual has made. Using the long-term storage capabilities of the cloud, it is possible to give current students access to discussions from other sections of the same course or even from previous years.

Several articles report the use of cloud software to encourage student collaboration. Spaeth and Black used Google Docs for cooperative learning in laboratory courses, including using spreadsheets to encourage collaborative work among students doing complicated math problems.[11] Abrams combined DropBox with the Blackboard course management system to allow students to share research data for inquiry-driven environmental laboratory exercises.[12] Abrams notes that a major drawback of this approach is that only one student at a time can enter data into the Dropbox account. With some cloud-based software multiple students can work together in a shared environment, which an instructor may choose to populate with the necessary specialized software and applications. Bennett and Pence point out that a cloud environment can be used to facilitate undergraduate research, especially on a small campus where an instructor is maintaining a heavy teaching schedule while trying to keep track of the progress by multiple students.[8]

Cloud computing can also encourage faculty cooperation within a course on a single campus or even across multiple campuses. Even before true cloud computing became available, chemical educators were experimenting with ways to use the Internet to encourage collaborative faculty work. For example, the Physical Chemistry Online Consortium (PCOL) was an attempt to support faculty at small departments who were teaching physical chemistry.[13] Often small departments might have only a single faculty member teaching physical chemistry, but by sharing resources and supporting collaborative activities among several institutions, the PCOL group was able to increase faculty interaction and create a richer educational environment. Increased adoption of the cloud can make these types of faculty collaboration more common.

■ USING THE CLOUD TO CREATE SPECIAL COMPUTING ENVIRONMENTS

Particularly in advanced chemistry courses, the instructor may wish the students to use specific software, like simulations, or molecular modeling. Normally, this would mean that each student would have to obtain appropriate software licenses and download the desired programs. Since most students today use multiple computing devices, this process would be repeated several times. The alternative is an on-campus computer laboratory where the machines are appropriately configured, but this would require all work to be done at that one location. As powerful computing techniques become more common in chemical research, it seems inevitable that they will be adopted for undergraduate research. This will require that students have access to specialized software, and computer processing power that is scalable on demand. Cloud computing allows a professor to create a cloud site, which is configured as needed. Then students would only need to sign into that site to have access from all their devices, as long as they have access to the Internet. Although not all software companies may currently offer a this type of site license, this is likely to change as the cloud becomes more popular.

Cloud computing is an excellent complement to mobile devices. Smartphones and tablets are widely used in chemical education,[14] but their capabilities can be extended by having data storage and data processing occur in the cloud. The cloud provides more processing power and data storage capacity than a typical mobile device, and the battery life of the device is extended by transferring the energy-consuming processing into the cloud. Cloud connectivity also means that students have access to their data from multiple devices. The combination of mobile device with the processing power and storage of the cloud creates a new model called mobile cloud computing (MCC).

■ POSSIBLE CONCERNS ABOUT CLOUD COMPUTING

Sultan reports that the most common concerns about cloud computing among educators are security and privacy. It is generally expected that major cloud providers will have better security than most campuses, but this question is especially relevant for cloud providers that store their data on servers located in countries where the privacy laws are different from those in the U.S. Another issue mentioned by Sultan is the fact that many cloud providers do not use an open-source standard interface. This makes it difficult (or impossible) to move from one provider to another, so the user is locked in.[3] Recently, the Apache Software Foundation (ASF) has released Apache Libcloud v1.0, an open-source library, which allows users to manage their cloud resources by means of a unified and easy-to-use interface.[15]

Cloud users require a fast and stable connection to the Internet and a dependable provider. Since some parts of the nation, especially rural areas, still lack good Internet connectivity, moving to the cloud will increase the digital divide that already exists between the digitally connected and those with limited access. In addition, if the cloud provider fails,

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even for a short time, this could bring an entire campus's essential operations to a stop. Sultan lists several major cloud providers that have had outages lasting several hours, including Salesforce, Amazon, and Google.[3]

CONCLUSION

As pointed out in a recent feature article in *Chem. Eng. News*, the chemical industry is increasingly moving toward using the cloud, and this even includes the pharmaceutical companies, where there has previously been hesitation due to security concerns. Chemical educators should be aware of this trend and at least consider introducing cloud techniques into their classes.[16]

Chemical educators are still in the early stages of exploring the potential educational benefits of cloud computing. It seems likely that in the near future every student in a class will have access to all of the resources necessary for the class, simply by accepting an invitation to join a cloud site. Digital data, lecture notes, laboratory results, mobile communications, and personal files will be instantly available, as well as access to online specialized services and any online database that could be connected by an API. All that remains to be found is the imagination to develop new ways to use this accessibility for chemical education.

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Notes

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