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Case study

Improving K-12 pedagogy via a Cloud designed for education

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ABSTRACT

Cloud computing offers an opportunity to improve K-12 pedagogy with services tailored to teachers' needs in individual classrooms. The Cloud can deliver services such as remote access to learning tools in a cost effective manner to school systems struggling with reductions in local and state funding. This article explores the distinct ways that a Cloud designed specifically for education can be applied to K-12 education's academic mission. It uses observations from a case study in North Carolina rural high schools using an educational Cloud called the Virtual Computing Lab to access dynamic geometry and algebra software.

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1. Introduction

"There's nothing that can be done remotely in the Cloud that couldn't be done better locally if you had unlimited resources."[1] Unlimited access to software, hardware, storage, networking capacity and, very importantly, technical support for each individual computer and server running—would render Cloud computing superfluous.

But the funds for unlimited computational resources do not exist and nowhere is that more apparent than in the educational sector. Funding tied to state allocations for public education has been substantially reduced with the last several years' economic recession. The Pew Center of the States (2012) estimated that in 2011–2012 thirty-seven states in the U.S. cut aid to local school districts (p. 9). At the same time, efforts toward integrating technology into pedagogy and curricula content have continued to become more sophisticated in facilitating learning. Reducing costs while protecting access to effective educational technology is the potential of the Cloud.

Cloud computing, having been a focus of corporate interest in recent years, is increasingly a subject of discussion in education circles. The 2011 New Media Consortium's Horizon Report for K-12 listed Cloud computing as one of two main technologies to watch for adoption into mainstream use within the next year (Johnson, Adams, & Haywood, p. 6). Much of the recent discussion highlights Cloud computing's application to educational administrative tasks—enterprise functions such as management and student enrollment registration—rather than its introduction into the academic side of K-12 education.[2] Where further Cloud implications in classrooms are discussed, the prevalence has been for the introduction of accessory and enabling technologies such as video and podcasts, shared slides, and communication facilitation rather than delivery of actual content and learning tools themselves (Smith, Davies, & Evans, 2012). Outside of the academic year, supplementary K-12 educational programs have begun use of Cloud computing to engage students in web based presentation of science in a project-based learning environment to encourage their interest in STEM careers (Malloy, Grant, & Bogues-Hill, 2012).

While similar goals of efficiency, effectiveness, and cost savings undergird both educational and corporate interests in Cloud computing, the academic side of education has specific needs that reflect the difference between the corporate bottom line of profit generation vs. education's bottom line of learning and knowledge production. Sultan (2010) discusses Cloud computing in relation to implementation in a university setting, and points to the need for further research in areas such as privacy concerns that may inhibit adoption of Cloud services in education. This article

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[1] Conversation with Henry E. Schaffer, Professor Emeritus of Genetics and Biomathematics at North Carolina State University.

[2] An example is North Carolina's Race to the Top initiative with the majority of its near term future goals for Cloud computing in the administrative dimension of public school system operations. http://www2.ed.gov/programs/racetothetop/phase2-applications/north-carolina.pdf.

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furthers that discussion by exploring the ways that Cloud computing can help K-12 education's academic mission by providing remote access to advanced learning tools, in a cost effective manner, to school systems struggling with reductions in local and state funding. The discussion is based on observations from a case study in North Carolina, now in its third year of Cloud implementation in K-12.

The case study uses an educational Cloud, the Virtual Computing Lab (VCL) developed by North Carolina State University (NCSU) in 2004 and available as Open Source from the Apache Foundation ("Virtual Computing Lab", para 1). In this case study, the VCL is used to provide dynamic visualization and simulation mathematics software to rural North Carolina high school 9th and 10th grade geometry and algebra classes as part of a project to improve student performance. The experiences garnered from this project's implementation in North Carolina high schools are used to highlight the benefits public schools derive and the challenges they must face in this next step in the integration of technology into teaching and learning.

2. Defining Cloud computing

Cloud computing is dynamic and, like other technological innovations, changes rapidly. Definitions for Cloud computing have been articulated differently by information technology researchers and professionals, but there is agreement on a central concept: Cloud computing refers to the use of remote servers over the Internet to provide on-demand access to software applications, hardware platforms, and infrastructure as services for users (Rindos et al., 2010; Schaffer et al., 2009; Vouk et al., 2009). The National Institute of Standards and Technology (NIST), a U.S. Federal government agency responsible for developing technology standards and guidelines, recently issued the following definition:

> Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction (Mell & Grance, 2011).

Fundamental breakthroughs in technology—high-speed broadband Internet networks and low-cost desktop and mobile computers—have expedited a profound shift in how computational resources can be allocated. Clouds build on economies of scale, offering remote access to software applications without local installation on users' workstations. In addition, vast arrays of remote hardware and infrastructure are made available to users and operated by Cloud providers. These provisions greatly reduce the costs per service below what can be achieved by individual institutional IT resources, especially for small and medium sized institutions (Sultan, 2011).

A true educational Cloud is not just Internet based computing. It is a Cloud designed to serve educational needs and to deliver these services at a cost level that education budgets can afford. Public Clouds generally meet the common base of user requests at an affordable level, but may not be designed to meet educational needs at affordable levels, or even to meet them at all. The VCL is one of the earliest Clouds to be put into production, and is the first Cloud to be developed focusing on education. The following sections discuss the benefits and challenges of bringing Cloud computing to public education through the lens of the case study, a National Science Foundation-funded project serving high school math programs in North Carolina.

3. "Scaling Up STEM Learning with the VCL": a case study

The lack of workers highly proficient in subjects leading to STEM-related careers (science, technology, engineering, and mathematics) is of concern in forecasting the future economic success of the United States. The National Science Foundation (NSF) has made increasing the STEM workforce a target of research funds in recent years (National Science Foundation, 2009, para 1). "Scaling Up STEM Learning with the VCL" is a NSF-funded project[3] to increase student motivation toward STEM professions, and their ability to qualify for them, by improving their geometry and algebra learning. These two courses lead to levels of math comprehension that are required for higher levels of math learning and ultimately STEM disciplines.

The project investigators, faculty researchers at NCSU, chose for their project four North Carolina rural school districts. All have high populations of underprivileged and minority students. Most report low pass rates in geometry and algebra as measured by end of curriculum exams. The cohort high schools make laptops available to every student during school hours and provide broadband Internet connectivity inside the school buildings. The project aims to improve 9th and 10th graders' math learning through the use of dynamic visualization and simulation software applications: The Geometer's Sketchpad 5 and Fathom 2 (Key Curriculum Press, 2010). Teachers are provided with professional development (PD) to help them gain proficiency in use of the software and related pedagogical practices in a weeklong, intensive summer PD institute, followed by a six-month online curriculum.

As indicated in the project name, "Scaling Up STEM Learning with the VCL" (ScalingUP) is designed to advance the development and widespread dissemination of an educational model that can have statewide, regional, and national application. Cloud computing, via NCSU's VCL, constitutes one of the scalable components of that model.

The VCL has been in production at NCSU since 2004, serving a campus population of over 34,000. It is unique in the emergence of Cloud computing in that is has been fully operative for eight years, serving educational needs remotely before the term "Cloud" was coined. The VCL has been adopted in a wide range of institutions across the country, from George Mason University on the East coast, North Carolina Central University representing the HBCUs (historically black colleges and universities) in the South, to the California State University system on the West coast.

The VCL was developed to remedy roadblocks to the timely provision of computational resources needed to fulfill NCSU's teaching mission. Campus computer lab machines were increasingly subject to internal software conflicts as faculty requested more applications. The timing of installation for new and updated software was hard to agree on among faculty and IT staff, and laboratory technicians were spending more and more time attempting to resolve such conflicts. New software programs required greater processing speed and memory and accelerated the replacement rate of lab machines, thus placing pressure on IT budgets. The result was unfulfilled pedagogical needs and escalating maintenance costs.

The problems that NCSU resolved with the VCL mirror those that face administrators and teachers across the public education spectrum. In the K-12 public arena, these problems are amplified by the tight budgetary restrictions that limit the purchase of software and equipment as well as the number of IT personnel available to each school district. Even where personnel hiring dollars are available,

[3] http://scaleupstem.ncsu.edu. This material is based upon work supported by the National Science Foundation under Grant No. 0929543. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. For more information on the project, visit http://scaleupstem.ncsu.edu.

finding adequately trained IT workers remains a challenge for most rural school districts.

Implementing the ScalingUP project in North Carolina high schools has produced both beneficial and challenging experiences with Cloud computing in K-12 education. We discuss in further detail below what this project has revealed to be of most importance to education: diversity of software applications, software license cost savings, security, extending machine life cycle, availability of broadband connectivity outside of school, affordability of class time delivery, and the cultural vs. technical barrier.

4. Benefits and challenges of Cloud computing in K-12

Wiebe and Hudnutt (2007) found that K-12 teachers and administrators saw the potential a Cloud technology platform like the VCL had to facilitate software and media deployment across school environments. "When I look at Cloud computing," says Ed Chase, the Chief Technology Officer (CTO) for Edgecombe County School District, a participant in the current NSF project, "I think of economies of effort along with economies of scale. If I need to deploy 3000 new Netbooks, each has to be configured for student use. Using the VCL for software that resides in the Cloud would mean I could mount two to three major applications at most on their laptops and greatly minimize the amount of time, effort, and human resources required" (personal communication, March 19, 2012).

4.1. Diversity of software choices

Diversity of approaches to learning is the bedrock of effective education. The flexibility of choosing diverse software applications is a critical component of an educational Cloud. Unlike the corporate sphere where economies of scale can be realized by such measures as a top-down dictation of homogenous software or operating systems, education tends more to a bottom-up adoption of software and hardware. While K-12 education often takes a more uniform approach to textbook adoptions and hardware and software choices than does higher education, there remains the need for K-12 teachers and students to have flexible access to applications and methods.

Providing a range of software has its challenges. Different software applications often conflict with other programs on the same machine, creating time-consuming work for IT staff to get all the desired software running smoothly. Historically, underfunded school district information technology (IT) personnel will "lock down" all installed programs on the laptops at the beginning of the school year. This means that if a teacher finds a software program that she wishes to use with her students, it cannot be added unless agreed to by the IT department. As a result, IT personnel can inadvertently restrict pedagogical practices and approaches that may be beneficial, and contribute to the types of bottlenecks that too often occur in providing tools and information to students in public schools (Wiebe & Grable, 2007).

The pedagogical opportunities of Cloud computing resonate strongly in relation to diversity of software. Learner-centric and student-centric practices have come to dominate attempts to improve teaching and learning in the U.S. Much of the educational software being devised takes advantage of interactive modes of engagement with the subject. Experience with the Cloud at NCSU has shown that teachers will change their pedagogical practices and add other software programs to existing applications when problems with software conflicts are eliminated.[4] In the case study in North Carolina schools, Geometer's Sketchpad and Fathom enable geometry and algebra students to create dynamic graphs and teachers to create learning activities that maximize the visualization and simulation capabilities of the software. Students work together on shared laptops, allowing the teacher to provide individualized responses to group work in the course of the class period. Results from the implementation of the project, now finishing its third year, show significant changes in teaching practices in the classroom; further analysis will be applied when end of curriculum exams in algebra are made available to the project's researchers. A central advantage offered by Cloud Computing is making the cost of providing advanced learning applications, both in amplifying the use of software licenses as discussed in Section 4.2, and in maximizing the efficiency of IT personnel affordable.

Cloud computing such as the VCL circumvents the barriers associated with insufficient IT support staff in chronically underfunded K-12 schools through an architecture that requires only a one-time installation of an application on a remote server to serve wither a single or multiple school districts. Any number of software applications can be loaded on Cloud servers without any worries about performance diminishment due to software conflicts because each application is in effect stored on a separate computer in the Cloud. Thus, the diversity of approaches to teaching and learning critical to effective education is upheld without placing undue burdens on IT staff and budgets. Keith Medlin, CTO of the Chatham County School district, which will be using the VCL to provide Fathom software in the project's algebra cohort, sees Cloud computing in K-12 as the best way to insure that instructional technology to improve learning continues to be available to his district's teachers: "We have the 1:1 laptops for all the students and teachers, and they need to be set up so they can be effective in teaching. Otherwise, laptops are available but they don't get used" (personal communication, March 30, 2012). As is reflected in Medlin's statement, utilizing computer technology effectively in the classroom continues to be of concern in educational circles (Wachira & Keengwe, 2011).

An additional advantage that the VCL brings to education can be seen in the use of multiple versions of the same software. Vendors often release software updates, but not all instructors may be ready to change to a new version. At NCSU, multiple versions going back one to two years continue to be available at the same time as the latest update. With the VCL, there are no conflicts between versions as would exist on campus computing lab machines since the software is loaded and accessed on separate remote computers. With an educational Cloud, educators, rather than the IT staff or commercial vendors, decide on the best instructional technology applications at any given time (Stein & Schaffer, 2010).

4.2. Software license cost savings

One of the questions frequently asked is how Cloud computing affects the purchase of software licenses. The VCL does not circumvent any license requirements. In the NSF project schools, the licenses for Geometer's Sketchpad and Fathom are negotiated with the publisher based on the number of students and teachers served, and the publisher allows delivery both via the VCL and local installations.

There are, however, cost savings to be legitimately realized in the use of the VCL. In the traditional workstation setup, software is loaded on each individual computer, for personal use or on computing lab machines. The software is available whenever desired by the owner or lab user. When the user is away from the computer

[4] For example, an instructor in NCSU's College of Natural Resources began using the Cloud/VCL to provide ArcGIS to his students, and because of its ease of use then added Excel into the application image on the VCL remote servers. This represented a change in his teaching strategy that proved very useful (Dr. Hugh Devine, personal communication, May 2007).

or using another set of applications for a period of time, the loaded software goes unused.

This is one arena in which savings can be substantial for education. Software that has a negotiated number of "seat" licenses loaded on the VCL only restricts maximum limits for concurrent use. As an example, if there are fifty seat licenses for Geometer's Sketchpad 5 at Edgecombe County School District, Mrs. Adams' and Mr. Jones' 10:00 a.m.–11:30 a.m. daily geometry classes with twenty-five students each accessing the application on the VCL will maximize the available software during that time period. Others wanting to use the Geometer's Sketchpad 5 right then will have to wait. However, the same licensed software will be available for fifty more students in the 11:30 a.m.–1:00 p.m. geometry classes taught at the school, even if those licenses were used in other classrooms (and subsequently by different students) earlier in the day. This issue of concurrent use is critical: a school could potentially buy fifty seat licenses that would be used by multiples of fifty during the same day, and in fact throughout the night if desired. In many cases, vendors negotiating with the VCL will provide a network license at a higher rate to compensate for this multiple use, but generally this still provides a significant advantage for economically pressed schools. As an example, school districts could be looking at the difference of paying $5000 for the purchase of fifty network licenses for $100 each, against paying $10,000 for the purchase of five hundred individual licenses for $20 each. It must be noted, however, that software vendors are skittish about the Cloud licensing model and may attempt in the future to undermine these kinds of savings through shared licenses. As Cloud computing is a relatively young technology, issues such as software licensing will take time to sort out, and the education sector must remain engaged.

Schools can determine the best plan for access to educational software by keeping in mind that the VCL is designed as a computer *augmentation* tool, not as a computer *replacement* tool. If the best solution, pedagogically and economically, is to load student and teacher laptops with a specific software application, then the Cloud is not the right choice. In the NSF project, Geometer's Sketchpad 5 and Fathom use simulation and visualization modes of teaching math principles to students who are accustomed to interactive and dynamic multimedia. Applications such as these run well over the Internet via the VCL. Software tools that require very fast and specialized connections, such as video editing and gaming graphics, do not currently run effectively on the VCL.

The needs of particular populations and institutions dictate whether to provide tools via the VCL or locally. Currently at NCSU, for example, ordinary office productivity tools such as word processing and spreadsheets are not provided by the VCL, as essentially all of the student population owns computers with those programs installed. On the other hand, the community colleges in the NC Community College System partnership provide those same office tools via the VCL because student ownership of computers with those tools is not as pervasive and there is a need to standardize software versions used for the courses that teach the use of those tools (State of North Carolina, 2009, p. 13).

For K-12, the same considerations pertain. If a limited number of classes is using a highly specialized learning tool, for example, it might make sense to deliver it using the VCL rather than to install it on all student laptops. Cloud computing is most effective when it is understood and implemented strategically.

4.3. Security in K-12

Security of data and transactions are concerns for every user of networked computation. In both the education and corporate realms, protection of sensitive information is paramount. In the educational realm, however, there's another issue when Cloud Computing is being considered.

Initially, three of the four school districts in the NSF ITEST cohort did not want to participate in the Cloud computing component of the project. The primary reason: CIPA, the Child Internet Protection Act, Public Law 106-554 passed by the U.S. Congress in 2001. CIPA is aimed at public schools and public libraries with federal funding tied to its implementation. Virtually all public schools have implemented CIPA to limit sites on the Internet accessible to students during school hours on school property (Jaeger & Yan, 2009).

CIPA requires each school district to approve its form of compliance. Each district in a region or state may have very different ways of constructing firewalls or filters to achieve that compliance. At the beginning stages of the ScalingUP project, three of the four district CTOs in the NSF grant cohort claimed that they could not make their firewalls impervious to student hackers; they expressed the fear that having to configure the firewall to allow a browser and Remote Desktop Protocol access to the VCL would compromise their CIPA compliance. Most of the high schools in these districts had installed an earlier version of Geometer's Sketchpad on the student laptops. The grant project paid for licenses for Geometer's Sketchpad 5 to be loaded on student laptops in the project cohort in those three school districts, and the schools incurred the additional expense to purchase licenses to supply all students in math courses across the district with the software.

The lone district that chose to use the VCL to access Geometer's Sketchpad had a CTO who embraced the potential benefits that the Cloud offers, and configured the district's firewall to allow access to the VCL. He saw that many additional resources were available via a Cloud delivery system, and wanted the opportunity to try it out with the help of the VCL development team at NCSU. The NCSU team configured the VCL software environment used by the school district to block any access to websites beyond the VCL.

At the time of this writing, the district has used the VCL to access Geometer's Sketchpad for almost two years, and no breaches of CIPA have occurred. In light of this clean track record, two of the three remaining school districts have agreed to use the VCL for access to Fathom, the algebra software being implemented for the next academic year (the remaining school's CTO wants to restrict the firewall to existing open ports). The history of no compliance glitches experienced by Edgecombe added to the fact that CTOs adopting VCL use are now working with improved broadband network connectivity in their schools, which provides greater assurance that Cloud-based instructional software can be readily accessed.

4.4. Extending machine life cycle

The Cloud opens the door to low cost computing power. Because the computational power needed to run applications is provided remotely, schools can save costs through the use of older and less powerful computers. Lengthening the life of hardware substantially lowers the cost of ownership. Ed Chase at Edgecombe County reported that his district had to extend the replacement cycle of student computers to at least 48 months because of reductions in educational funding. With the VCL in place, removing the need for the higher processing power and larger memories and disks of newer machines, his plan is to run computers until they die.

In the same vein, greater equity for students whose families own computers is gained: those who cannot afford to update to new expensive, more powerful computers needed to adequately run more advanced software programs are no longer left out of the loop. The same software tools can be operated via the VCL across the board, whether the computer is six months or six years old.

Cloud computing also eliminates what some call "platform wars." Apple-based programs do not run on Windows computers, nor does Windows software run on Apple computers without add-on software capabilities. The VCL is "agnostic" when it comes to the user's platform; any software that can be loaded in the VCL can be used on a user's Windows, Apple, Linux computer or most thin clients.

4.5. Availability of Internet connectivity outside schools

The VCL provides access to learning tools 24 h a day, 365 days of the year, and is specifically designed to enable users to work from anywhere at anytime. Yet, the digital divide of haves and have-nots is still operative in the U.S., even with advances made in providing equal access to computational resources for all socioeconomic groups. Among the NSF project's school cohorts, for example, there are significant differences between the network resources available to the Mooresville Graded School District in the Piedmont region of North Carolina and those available to the Edgecombe County School District in the eastern part of the state. In the more affluent community of Mooresville, Scott Smith, the CIO, reports that there is virtually one hundred percent highly reliable broadband Internet connectivity in every residence of the students, as the town has created its own network provider for that purpose. In turn, all teachers routinely assign homework that use computers and the Internet (personal communication, March 23, 2012).

Edgecombe and Greene Counties encompass significantly less affluent populations than does the Mooresville Graded School District in Iredell County. Many of the homes in Edgecombe and Greene do not have broadband Internet connectivity. In addition, interviews with Edgecombe teachers revealed that approximately twenty percent of students did not take their laptops home with them, and for that reason the teachers did not assign homework that involved using Geometer's Sketchpad and Web course materials that were used in the classroom. Those students were either ineligible to take their laptops from the school because of disciplinary problems, or because their parents would not agree to take on the responsibility of their doing so (Ware, 2010). In Edgecombe, the students have access to the software via the VCL, and therefore can use the math software at public libraries or on computers made available at their schools when classes are over for the day. In all these cases, it is important to recognize that Cloud computing requires broadband access to the Internet, and the digital divide, which is still operative throughout the United States, will determine who has ready access and who does not.

4.6. Affordability of class time delivery

Classes are held on a regimented schedule in K-12, and any instructional technology that can facilitate learning must be available according to that schedule. In the high schools in the NSF project, geometry and algebra classes are taught five days a week, meeting for 90 min periods 5–6 h during the day. If the teacher is using Geometer's Sketchpad or Fathom on the VCL, the software is pre-loaded on the Cloud servers to meet the need for guaranteed on-time delivery. For example, if a teacher has geometry class every day from 10 a.m.–11:30 a.m., all of the students registered in her class will have near immediate access to the remote software application the teacher has designated.

Why pre-loading? When each remote server is prepared to meet the software request, there is a lag time that can last between 3 and 10 min using the current VCL storage technology. That is a load time that the VCL development team is working to reduce, but it currently means that to guarantee a 1-min access time to students and teachers (about the time it takes to log in), remote servers must be reserved in advance for those class periods.

The VCL accommodates this need by its use of "block allocations": instructors make requests for specific days and times for access to specified software and the student registration directory is tied to the VCL so enrolled students will have immediate access during class times. In order for a Cloud delivery system to work, end users must be registered with the provider. In the case of our NSF project schools, their student enrollment registry (LDAP and other systems) has to be connected to the VCL management node to allow students to log in for access using their school login ID and password. This is not an arduous process but it must be done in a timely and comprehensive manner. When changes occur in the student registration through transfers and so on, the LDAP, including class rolls, must be updated or access to the Cloud will be blocked for the affected students.

Education's need for guaranteed time of day access in the Cloud is distinct from corporate use of the Cloud. This can be understood in two parts: (1) the need for delivery of specific software at pre-determined times throughout the day is critical to a teaching mission and (2) while corporations needing a guaranteed timed access to specific Cloud services would have the funds for excess charges over basic service, a premium for class-time access would be unaffordable for public education.

Corporate Cloud needs are met by commercial public Cloud services, such as those provided by Google, Amazon, and IBM. Many of these commercial Cloud vendors have entered the educational realm in areas such as large-scale enterprise functions like and administrative operations, and are now looking to move into the academic side of Cloud provision. Yet, commercial Cloud services, while very inexpensive at the onset for large-scale homogenous services, could start to exceed educational budgets when their SLAs (Service Level Agreements) need to be tailored for specific teaching requirements. In order for a public Cloud to provide widespread customized service of that kind, it would have to charge more than general subscription prices. From a pedagogical standpoint, paying a premium for what constitutes basic, daily service for educational institutions would prove prohibitive. Having that guaranteed access at an affordable cost is critical to the success of using Cloud-delivered technology in education.

The VCL, as a private Cloud designed specifically for public education, recognizes the need to protect the growing uses of technology in teaching and learning by allowing educational systems to benefit from the economies of scale built into Cloud architectures without requiring extra cost arrangements. The VCL code is provided at no charge (Open Source) through the Apache Foundation, and researchers at NCSU have built extensive resources to help educational institutions utilize the VCL Cloud effectively by joining with other institutions regionally to share resources. The North Carolina Community College System partnership, for example, currently uses the VCL on twenty of its fifty-eight campuses with its Cloud servers hosted centrally, a case in point of a consortium approach to eliminating redundancies and maximizing scarce IT personnel. As public education, and particularly through K-12 institutions, becomes more invested in using Cloud services, institutions must pay careful attention to the real costs of services that are required to fulfill their mission and be vigilant about how their future needs for services can grow from their present situations.

4.7. Cultural vs. technical barriers

All innovative technologies are disruptive in that they take peoples' established modes of working and require them to change what has become habitual. While this is seen as an advantage to product producers at the edge of technological transformations, it can be unsettling, to say the least, to the human beings who have to adapt their methodologies and routines to meet them. Within the more than seven years of disseminating the VCL to academic institutions, one of the central insights we have gained is that the barriers to adoption are as much, if not more, cultural than technical.

Teachers and IT personnel, like their counterparts in the corporate sector, have evolved ways of working in part to suit their styles and in part to meet the serious demands and pressures of the job. Asking them to accept something as fundamental as no longer having software programs loaded and managed on the desktops is a significant shift in the way of working, even if it can quite quickly become routine and open up possibilities of expanding pedagogical choices.

Despite genuine pedagogical and economic advantages Cloud computing can bring to K-12 education (or any level of education), any great innovation can fail if it ignores the needs of its users to adapt. Meeting this need requires recognition of the human reluctance to change, even when the benefits are evident. One way people are encouraged to adopt new technologies is through the example set by a peer: critical mass builds when a teacher or IT staff member gets colleagues interested in trying for themselves something they see meets their needs more effectively.

Finally, adequate training and onsite support in the use of Cloud computing are essential, as is the presence of a "champion" in the form of a CTO or superintendent who can see the potential and is willing to carry the initiative forward. Neill Kimrey, Director of Instruction Technology for the North Carolina Department of Public Instruction, sees Cloud computing as essential in providing advanced learning tools such as Geometer's Sketchpad and is willing to fight for it: "We can't afford to give students state of the art tools to use and learn from on a wide spread basis. When you really talk about scaling this [use of math learning tools] from these schools to the state level, the state is not going to be able to purchase them, and districts can't purchase them. So, we are going to have to rely on solutions like this. . .. It's like everything else in our life is on the Cloud, except for what we do at school. We bank online. We do our Many of us don't realize it, but our home phone service now runs over the Internet through the Cloud. I mean; it's here. It's just like in everything else, K-12 education tends to be about 20 years behind. And, I'm really trying to push us forward with that" (personal communication, June 18, 2012).

5. Conclusions

Cloud computing can provide computational resources for teaching and learning both cost-effectively and with the flexibility that education requires. This article has addressed the benefits and challenges that K-12 education faces when considering the adoption of Cloud computing for pedagogical aims in the following areas.

Diversity of software applications: Diversity of applications and approaches to learning are the hallmarks of effective education. Yet, the cost of advanced learning applications as well as software conflicts on school and student computers can severely limit the range of learning tools made available in K-12 education. Cloud computing offers a cost-effective way of circumventing such restrictions and of providing richer curricula to all school systems, and especially to the less affluent school systems.

Software license cost savings: Schools can share software applications legally and cost-effectively using the Cloud by purchasing a limited number of "seat" licenses and managing the concurrent use of the software. Determining what learning tools are best installed locally and what are effective via remote access is important in the effective use of Cloud Computing in K-12.

Security: Public K-12 education is subject to the federally mandated CIPA, the Children's Internet Protection Act. Cloud computing, as seen in the implementation of the VCL in Edgecombe County high schools, can be configured to meet the CIPA compliance policies put in place by school districts.

Extending machine life: Significant cost savings can be realized through Cloud computing by decreasing the replacement rate for student computers. Those savings are amplified by the reduction in IT personnel costs related to maintaining computer labs and updating software. The VCL is "platform agnostic," and Windows, Apple, and Linux machines can access the Cloud. Student access to software is made more equitable across socioeconomic differences since older, less powerful computers can remotely operate advanced software.

Availability of broadband connectivity outside of school: The VCL is specifically designed to provide access to learning tools from anywhere at anytime. Yet, economic realities mean that available broadband Internet connectivity in students' homes varies with the affluence or impoverishment of the district. This can result in teachers not assigning homework using the software used in the classroom, and the advantages of Cloud computing to further enhance learning can be decreased.

Affordability of class time delivery: Face-to-face education employs strict time periods during which software must be available with minimal delay. Using the VCL, a Cloud designed specifically for educational needs, block allocations allow teachers to register their students and make pre-loaded software remotely available in less than a minute. Public commercial Clouds may charge a premium for such service that K-12 could ill afford.

Cultural vs. technical barrier: Impediments to the effective use of new technologies are as often cultural as they are technical. Job pressures make people reluctant to change their work habits and tools. Teachers can be averse to learning a new software program and IT personnel can adopt policies that restrict the availability of learning practices that improve student learning. The implementation of a new technology such as Cloud computing requires that educational leaders be cognizant of the element of human resistance to technological change and provide the training and environment that can ameliorate it.

K-12 administrators and personnel must also be careful to discern what truly advances their academic mission and what does not when it comes to Cloud computing. The many challenges discussed above should not be glossed over. Further research into Cloud delivery in K-12 education should include explorations into the changes teachers make in their classroom teaching in response to changes in the way students are learning—or not learning—foundational mathematics, as well as the impact Cloud delivery may have on greater advancements in pedagogical effectiveness.

Education will move in the direction of Cloud computing for the reasons of cost containment and scalability discussed. Helping public schools manage and extend limited resources is a primary concern in education. The promise of technological facilitation of learning is bearing fruit, as can be seen in instances such as the NSF cohort schools described in this article. Integrating those technologies in ways that K-12 can afford and sustain is one of the many potentials—and challenges—of Cloud computing.

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