Cloud Computing and K-12 School IT Infrastructure in Western Canada: From Challenges to Opportunities

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***Abstract*— This paper is based on the findings of an exhaustive study of all 75 large K-12 districts in Canada's three western-most provinces: British Columbia, Alberta, and Saskatchewan. This study encompassed over 1.1 million students and a geographical area of 2,258,483 square kilometers. Facilitating teaching and learning activities for so many students across such a large territory, with diverse provincial regulations, is an impressive feat achieved by the information technology leaders of the K-12 school districts. Multiple case study analysis, followed by correlation analysis, were used to explore the nature of IT infrastructure and cloud computing use in Western Canada. A data transformation model mixed methods triangulation design methodology was used. This paper discusses the strategies used in Western Canada to deliver educational technology resources through to students, teachers, parents, and district staff. The findings of this study are that cloud computing is the primary IT infrastructure in Western Canadian K-12 education. All school districts in the three provinces studied use cloud computing for some aspects of their infrastructure. In instances where cloud computing infrastructure is not used, school-level LAN and server infrastructure is used. In addition to being an alternative to cloud computing, the rare instances of school-level server use are either to supplement or complement a district's centralized cloud computing infrastructure, with cloud computing infrastructure existing in parallel.**

***Index Terms*— IT, cloud computing, K-12, infrastructure, network, educational technology**

I. Introduction

The proliferation of personal computing has produced dramatic changes in societies around the world. The proliferation of personal computing began with people's access to desktop computers, laptops, tablets, and smartphones [1]. At the end of the 20th century and beginning of the 21st century, the use of computing was largely linked to the programs and content available on the device in front of the user [15]. A device's usefulness was determined mainly by the software and programs on that device [4]. This is of course contingent on the device's hardware and ability to process the software in a timely manner. Today, and in recent years, the usefulness of a device is more a function of the software and content a device can access, rather than what is stored only on that device [9]. Today, the ability of a device to connect to content is paramount to a device's usefulness. It is increasingly rare for a device to operate in isolation. Rather, devices are connected to networks that make it possible for the device to access content [3]. The networks that a device connects to, via wired or wireless connection, can be Local Area Networks (LANs), Wide Area Networks (WANs), and/or the Internet [6]. This paper is based on an exhaustive study of all 75 K-12 public school districts in the three western-most provinces of Canada: British Columbia (BC), Alberta, and Saskatchewan. One of the questions this study examined was how Information Technology (IT) leaders and their staff deliver access to technology-enabled educational content to the over 1.14 million students spread across a geographic area of 2,258,483 square kilometers. As there are inherent benefits and challenges with each of the three networks, LAN, WAN, or the Internet, the researcher sought to understand the network architecture used to deliver access to educational technology. When was a LAN infrastructure used? When was a WAN used? When was the Internet used? Given the diverse software needs of K-12 districts, this study examined multiple aspects of districts' infrastructure, ranging from student record systems, to library systems, to email systems.

II. An Overview of Network Infrastructure Technologies Currently in Use

The following subsections present a brief discussion of the main network infrastructure types in use today, as well as a clarification of the different types of cloud computing. At the conclusion of this section, a brief overview of the typical organization of K-12 school districts in Canada and the United States is presented. A discussion of these organizational structures concludes this section as it provides important insights that illuminate the rationale behind the IT infrastructure used in K-12 school districts.

A. *Local Area Network (LAN)*

The most common type of network infrastructure in the world is the LAN. A LAN is used to connect multiple computing and electronic devices together. An example of a LAN is a home office with a desktop, a wireless router, a laptop, and a networked printer. The LAN permits devices on the

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network to share electronic resources, such as files or printing capability. LANs are found in homes, cafes, hotels, offices, etc. Though there is advanced LAN hardware available for specialized applications and/or large scale use, most LAN hardware is relatively inexpensive and therefore accessible.

B. *Wide Area Network (WAN)*

The WAN network infrastructure is an expansion of the LAN over a larger geographic area. A classic example of a WAN would be a fiber optic connection between office towers on opposite sides of a city or region. Though the function of a WAN is similar to that of a LAN, namely to provide electronic devices and their users with access to network resources, the implementation of a WAN is considerably more complex. Due to the considerable distances data must traverse, more advanced hardware is required for a WAN than a LAN. For example, while a typical LAN will use Ethernet cables, a WAN will more commonly rely on fiber optic cables due to the distance limitations of copper Ethernet cables [3]. The use of fiber optic cable then requires appropriate network hardware with fiber optic connections, which is more expensive than network equipment with only Ethernet connections. Moreover, there is a considerable cost in the installation of the cable across a wide geographic area, involving either the placement of cables overhead or underground. Due to the complexity, specialized nature, and cost, the use of WANs has been traditionally the domain of larger multi-million dollar organizations.

C. *The Internet and Cloud Computing*

At its core, the Internet is merely a network of interconnected computers around the world, similar in many ways to a LAN. One difference between a LAN and the Internet is the wide geographic distribution of these networked computers. Whereas a WAN typically consists of a dedicated, closed connection between distant sites, the Internet consists of multiple connections that allow data to hop from network device to network device in order to reach its final destination [5]. The implication of this is that the Internet permits users to have similar access to remote resources, without the high cost of a WAN. A limitation, however, is that the speed of access to remote resources over the Internet has historically been considerably lower than that of a WAN. Whereas an organization using a LAN or WAN can control its network infrastructure entirely, the use of the Internet moves control away from the organization.

The formal definition of cloud computing according to the US Department of Commerce's National Institute of Standards and Technology is as follows: "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. This cloud model is composed of five essential characteristics [on-demand self-service, broad network access, resource pooling, and rapid elasticity], three service models [SaaS, PaaS, and IaaS], and four deployment models [private cloud, community cloud, public cloud, and hybrid cloud]." (p. 2) [14]

D. *Cloud Computing Deployment Models*

The deployment models of cloud computing in the official NIST definition are presented in Table 1 [14]. These deployment models are at the core of this research on network infrastructure types in Western Canadian K-12.

TABLE I. NIST DEFINITIONS OF CLOUD COMPUTING

Cloud Computing Deployment Models	Definitions of Cloud Computing From the U.S. Department of Commerce's National Institute of Standards and Technology (NIST)
Private cloud	The cloud infrastructure is provisioned for exclusive use by a single organization comprising multiple consumers (e.g., business units). It may be owned, managed, and operated by the organization, a third party, or some combination of them, and it may exist on or off premises.
Community cloud	The cloud infrastructure is provisioned for exclusive use by a specific community of consumers from organizations that have shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It may be owned, managed, and operated by one or more of the organizations in the community, a third party, or some combination of them, and it may exist on or off premises.
Public cloud	The cloud infrastructure is provisioned for open use by the general public. It may be owned, managed, and operated by a business, academic, or government organization, or some combination of them. It exists on the premises of the cloud provider.
Hybrid cloud	The cloud infrastructure is a composition of two or more distinct cloud infrastructures (private, community, or public) that remain unique entities, but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for load balancing between clouds).

III. CENTRALIZED K-12 SCHOOL DISTRICT LEADERSHIP AND IT COORDINATION

Prior to a deeper examination of the technical aspects of the network infrastructure in K-12 districts in Western Canada, it is necessary to first understand the governance and leadership of these districts that influences this infrastructure. In North America, it is typical for the schools of a K-12 district to be governed by the jurisdiction's Ministry of Education or equivalent [7]. The schools of a district are centrally managed by a superintendent's office, which is responsible for ensuring that the schools within a district operate within the laws of the jurisdiction [8]. The central superintendent's office is responsible for the macro operations of the school districts, such as establishing teacher salaries, with individual schools having flexibility concerning minor decisions, such as determining costs of fieldtrips, coordinating small charitable activities, etc. This organization was suggested by the literature review and confirmed during the course of the study [10].

As this was the first study of its kind, there was no current literature available on the organization of K-12 district IT leadership and IT staff in the provinces of BC, Alberta, and Saskatchewan. A question the study examined was how K-12 district IT teams were organized. Were IT teams centralized, or was IT staff found at each school? While a detailed discussion of IT leadership in these districts is beyond the scope

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of this paper, in Western Canada, IT teams were centralized and operated from the superintendent's office. As needed, these IT teams would then work with schools to address schools' technology issues. The centralized leadership, as will be later discussed, is an important factor in the network infrastructure design of the K-12 districts in the study.

IV. Research Design and Methodology

This study followed a data transformation model mixed methods triangulation design methodology [2]. This study included all 75 large K-12 districts in BC, Alberta, and Saskatchewan and achieved a 100% participation rate. Over the course of a year, 80 semi-structured interviews were conducted with senior IT leaders from these 75 districts. These interviews ranged in length from 30 minutes to over an hour and a half. In addition to interviews, document analysis was used to verify and enrich the information of the interviews.

K-12 districts in the provinces of BC, Alberta, and Saskatchewan were selected because of their comparable characteristics. This is an essential feature of multi-case and cross-case analysis [12, 16]. These key characteristics were the availability of high-speed internet in the jurisdictions, comparable regulations, and the presence of school districts with student enrollment in excess of 5,000 students. These characteristics helped to ensure that districts with similar mandates and available internet connectivity were included in the study of IT infrastructure and cloud computing.

V. Findings and Discussion

Figure 1 presents the study's findings concerning IT infrastructure in Western Canada. This figure presents a summary of all 75 districts in the study's three provinces and reveals the extensive use of cloud computing. In addition to examining all 75 districts in aggregate, the study examined the three provinces separately, as well as four size groupings. These four size groupings were: 5-9.9K, 10-14.9K, 15-24.9K, and 25K+ students separately. Moreover, combinations of province and size groupings were analyzed. In total, the study's findings were examined through 18 different size and/or province groupings.

While the full details of the findings of these different groupings cannot be discussed here in a paper of limited length, the important revelation from the study was that cloud computing was the dominant infrastructure across all size and jurisdiction groupings. Differences primarily existed in the type of cloud computing infrastructure used (private cloud, community cloud, or public cloud). The use of on-premises school level LAN was found to be limited, regardless of a district's size or location. WAN use was not found. The following subsections will discuss these findings and the implications further.

A. .The Limited Use of On-Premises School-Level LAN

As is evident in Figure 1, the use of on-premises LAN was minimal when compared to the use of cloud computing for hosting and delivering core aspects of K-12 IT infrastructure. Each school in a K-12 district had a LAN as a means of connecting devices and providing Internet access to students and staff. The on-premises school LAN was a combination of wired and almost always also wireless infrastructure. The role of the LAN was critical in terms of providing such network access. However, in an overwhelming majority of districts, educational technology resources, such as library system content, Learning Management System (LMS) content, Student Information System (SIS) content, etc., was stored in a central data centre for the district, outside of the on-premises LAN of each school.

B. The Extensive Use of Cloud Computing

Every district in this exhaustive study of the 75 large public K-12 districts in the provinces of BC, Alberta, and Saskatchewan used a form of cloud computing in several IT infrastructure domains. This is clear in the IT infrastructure domains of SIS, financial systems, email systems, and website hosting where the percentage of K-12 districts using cloud computing was 100%. In the other IT infrastructure domains of the study, cloud computing use was still by far the most common platform. LMS, library services, and authentication/user login information were the other IT infrastructure domains examined in this study, and all three of these domains had over 90% of the school districts using a cloud computing platform.

C. Complementary or Supplementary Use of Infrastructure Platforms

The representation of this study's findings in Figure 1 is in bar graph form, instead of pie chart form totaling 100%, or similar, due to the complementary and supplementary use of IT platforms to meet school district needs. Most often, cloud computing versus on-premises school-level LAN infrastructure is a dichotomy where districts will use one infrastructure platform or the other. However, in certain instances, school level LAN infrastructure was used to complement or supplement the district's primary cloud computing infrastructure. For this reason, the IT infrastructure domain totals often exceed 100%. Similarly, the multiple types of cloud computing presented in Table 1 were used in a complementary or supplementary manner by districts.

An example of the complementary or supplementary use of on-premises school-level LAN in conjunction with cloud computing is found in the financial infrastructure domain. Though every school district in BC, Alberta, and Saskatchewan used software on a cloud computing platform for financial software, 5% of districts also used an on-premises school level financial software package. Whereas the cloud computing financial software was for major financial operations, such as payroll, smaller on-premises school-level software packages were used for smaller accounting tasks, such as the management of petty cash funds.

Another example of the combination of on-premises school-level infrastructure to complement or supplement district-managed cloud computing infrastructure is found in the LMS infrastructure domain. In this domain, LMS software is usually managed by the central staff of the superintendent's office and available to schools via cloud computing infrastructure. In the 4% of districts that ran LMS software at the school-level, one of

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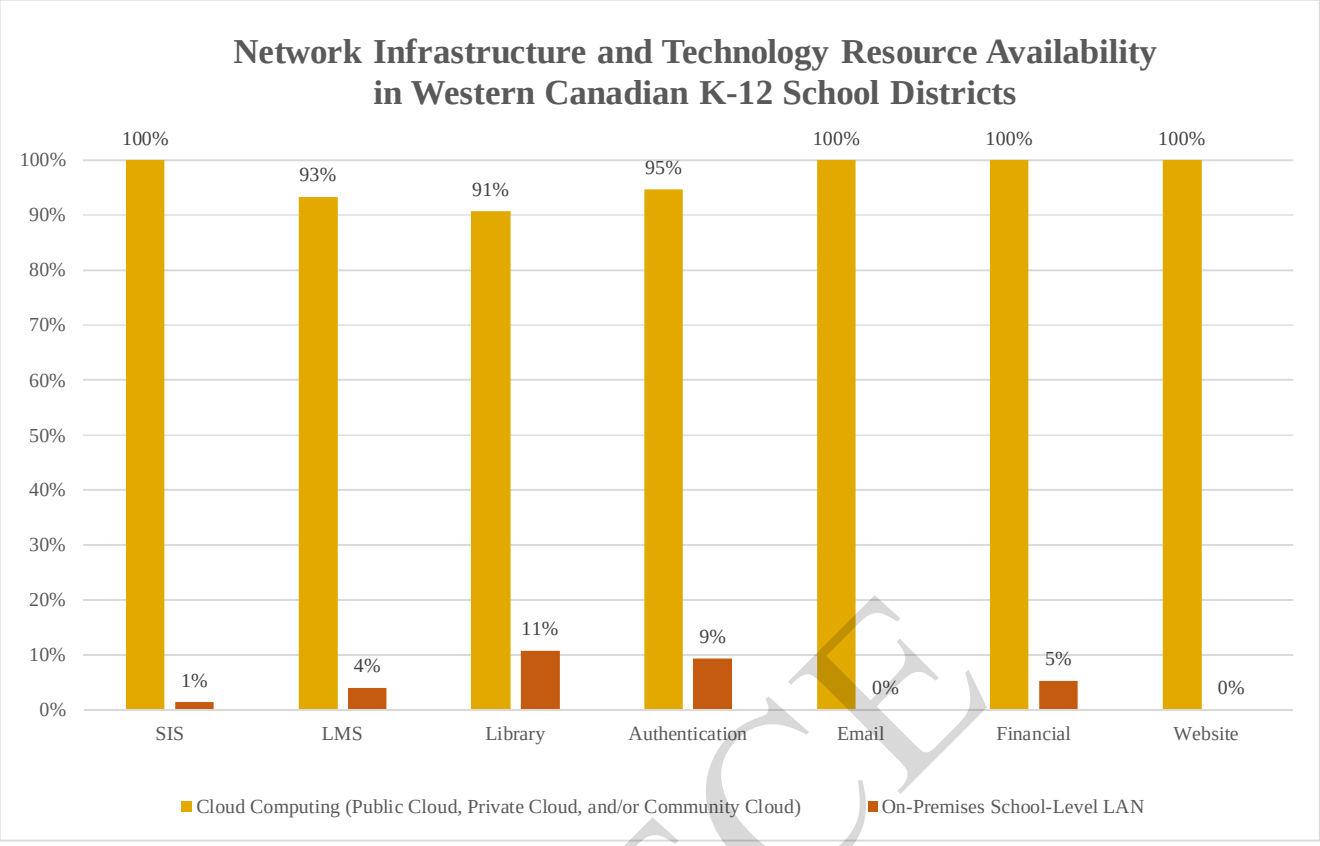


Fig. 1. Cloud computing versus on-premises LAN IT infrastructure.

the reasons cited by district IT leaders was the greater freedom a school-level LAN installation gave to advanced users who wanted to manipulate the LMS themselves. Moreover, the school-level LAN-based LMS could be managed directly by the advanced end users, without waiting for the availability of district IT staff. Another reason mentioned by study participants for the use of a school-level LAN over a cloud computing option was the greater network access speed possible when content is stored locally, on the LAN of school. Whereas modern LAN networks range from 100 Mbps to 10 Gbps, typical Internet connectivity in Western Canada ranges from 20 Mbps to 150 Mbps [11, 13].

D. The Implications of a Centralization of IT Resources

The decision of Western Canadian K-12 districts to centralize their IT systems in school district private cloud data centres, community cloud, or public cloud is the result of a confluence of factors. These factors include centralized leadership, geographic considerations, as well as economies of scope and scale.

1) Centralized Leadership and Geographic Challenges

The centralized leadership of public K-12 school districts in Western Canada provides an opportunity for consistency and a streamlined coordination of all of a districts' schools from a central office. This helps ensure that the practices of all of a district's schools are aligned with the laws/requirements of the jurisdiction's Ministry of Education and the vision of the district's leadership. This centralized leadership structure provides many benefits and efficiencies and is therefore the most common organization of school districts in Canada and the United States. This central organization of school districts also creates conditions in which on-premises school-level LAN IT infrastructure becomes far less desirable than centralized cloud computing IT infrastructure, be it in the form of public, private, or community cloud.

Given the central organization of K-12 school district leadership, including IT leadership, the management of IT systems located on servers within each school would require a phenomenal effort. To ensure consistency across a school district, technicians would be required to manage separate instances of SIS, LMS, financial systems, etc. at each school of a district. Compounding this challenge is the large geographic area over which the districts' schools are located. Moreover, given the northern latitude of Canada, the winters are regularly harsh and travel on frozen roads can be treacherous at times of the year. The central organization of K-12 school districts in Western Canada and the geographic factors, such as distance and climate, create conditions which make on-premises school-level LAN infrastructure a less desirable alternative to centralized IT infrastructure that can be accessed over the Internet.

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2) Inherent Advantages of Cloud Computing Infrastructure

Cloud computing IT infrastructure, in its various deployment models described in Table 1, has inherent efficiencies that are well documented in academic and practitioner literature. The extensive use of cloud computing in K-12, as presented in Figure 1, is therefore not surprising. By centralizing the management of IT infrastructure, away from separate servers at each school towards multiple servers within a district's data centre, typically located at the superintendent's office of the district, there is a considerable reduction in IT administrative effort required. Patching, updating, and maintenance can be performed for all of a district's users simultaneously at the superintendent's office data centre by the district's IT staff. Alternatively, maintenance can be further reduced when public cloud infrastructure is used, such as Google's G Suite or Microsoft Office 365, where Google and Microsoft, respectively, perform the patching, updating, and maintenance on the servers used by the district.

In the same way that the operation of a private cloud central data centre at the superintendent's office represents a reduction in maintenance efforts over school-level server management, the use of public cloud infrastructure represents a similar savings of effort. In public cloud infrastructure environments, updates and patches are applied to multiple customers simultaneously. This is particularly relevant in the current era of cyber threats, where it is important for organizations to address newly uncovered vulnerabilities in a timely manner [4]. Whereas larger organizations, such as Google and Microsoft, have the financial resources to properly staff IT infrastructure and IT security teams, it is difficult for public sector K-12 educational organizations to have equivalent resources.

Lastly, in Western Canada, Google's G Suite or Microsoft's Office 365 are available free of charge to qualifying educational organizations, further underscoring the economic argument for the use of public cloud computing in education. The availability of these products to qualifying educational institutions is a reflection of the economies of scope and scale enjoyed by Google and Microsoft. As is characteristic of cloud computing infrastructure, the scalability of cloud computing infrastructure means that this free initiative for K-12 schools represents only a negligible cost to Google and Microsoft. At the same time, this initiative introduces potential future customers to Google and Microsoft products, as well as aligns with these companies' philanthropic initiatives of supporting children's education around the world.

E. Distinguishing between Private Cloud, Public Cloud, Community Cloud, and Hybrid Cloud Use

For the purposes of parsimony, and clarity in the juxtaposition of cloud computing to on-premises LAN infrastructure, Figure 1 presents a summary of the extensive use of cloud computing in Western Canadian K-12 school districts. The following subsections will briefly discuss the typical applications of each deployment model of cloud computing.

1) Private Cloud

Private cloud was the most commonly used deployment model of cloud computing in Western Canadian K-12 districts. It also represents a more gradual, evolutionary transition away from the on-premises school-level LAN and server environment which predated cloud computing. Private cloud allows district IT staffs to have complete control of the hardware and software, while simultaneously providing the benefit of centralized management.

2) Public Cloud

Contrasting the somewhat evolutionary nature of private cloud district data centre-based infrastructure, public cloud is more revolutionary. Public cloud infrastructure represents a considerable departure away from school district controlled infrastructure to vendor controlled infrastructure. The most common use of public cloud infrastructure was for student email. This is reasonable given the large volume of students in the Western Canadian K-12 school districts, with some districts exceeding an enrollment of 100K students. Public cloud was typically used in situations where a district would be ill-suited to provide a comparable level of service from its superintendent's office-based private cloud data centre. Email storage for 100K+ users is one such example.

A finding of this study was that as districts became more comfortable with the use of public cloud, and relinquishing control of software and hardware to the public cloud vendor, districts embraced public cloud across more IT infrastructure domains. In the LMS, library, and financial systems infrastructure domains, approximately 20% of districts used public cloud.

3) Community Cloud

Community cloud was the least commonly used form of cloud computing in the study when compared to private and public cloud, though it was prominent in the SIS infrastructure domain. SIS infrastructure in the province of BC represented nearly all of community cloud use in Western Canada. In this one province, 88% of K-12 district SIS infrastructure was delivered using community cloud. The use of community cloud for student record management is effectively an extension of districts' transition away from multiple school-based servers to centrally managed servers. The impetus for community cloud SIS infrastructure in BC was to streamline the management of student records further, especially when students moved between school districts. The management of the community cloud infrastructure for SIS is handled centrally by the BC Ministry of Education on behalf of multiple school districts.

Though there are benefits of efficiency and consistency to the centrally managed community cloud SIS system, limitations are also present. The community cloud SIS infrastructure has financial resource constraints as it is effectively a central data centre operated and staffed by the Ministry of Education. An additional limitation, shared with public cloud infrastructure, is that individual districts lose control over full customization of the user experience. The appeal of community cloud infrastructure for broader use is therefore tempered by the fact that it has neither the compelling financial appeal of public cloud, nor the customizability of private cloud. For this reason it was found in only limited use in Western Canada.

4) Hybrid Cloud Use

Western Canadian K-12 districts combine multiple infrastructure platforms to deliver the IT services required by

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the students and staff of their districts. As discussed previously, the complementary and supplementary use of cloud computing with on-premises school-based servers is an example of this. Within the broader heading of cloud computing, K-12 districts also used combinations of private and public cloud within infrastructure domains, such as email, to overcome challenges associated with either infrastructure platform. In the email domain, especially in BC, student emails were commonly delivered using public cloud infrastructure, while staff emails were almost always delivered using private cloud infrastructure. The reason for the use of private cloud infrastructure for staff emails is for districts to remain compliant with provincial regulations concerning privacy and data residency. In this example, the use of a hybrid cloud of both public and private cloud allowed districts' IT teams to deliver critical IT infrastructure services while remaining compliant with the regulatory requirements of the region.

VI. Conclusion

The delivery of IT services to K-12 districts in Western Canada is challenging due to scale, scope, and geography. In this study's three provinces of BC, Alberta, and Saskatchewan, the IT infrastructure of all 75 large school districts was examined to better understand how IT leaders and their teams overcome the challenge of facilitating teaching and learning activities for over 1.14 million students across a northern region of 2,258,483 square kilometers. Rather than trying to manage multiple servers and complex infrastructure environments in all district schools, Western Canadian IT teams were found to rely on centralized data centres that were accessible via the Internet. School-level LAN infrastructure was used primarily as a means of providing network access to the Internet for staff and students. District IT resources, such as SIS, LMS, library systems, etc., were then delivered using cloud computing infrastructure and could be reached through the Internet from each school. When appropriate, combinations of different cloud computing and/or school-based LAN infrastructure were used to overcome problems associated with a single infrastructure platform. The result of these carefully crafted district IT environments is a robust technology foundation that supports the teaching and learning needs in schools. Despite being spread over a large and at times harsh geography of millions of square kilometers, students in Western Canada continue to have reliable, secure access to the educational resources they need to reach their full potential as scholars and citizens.

Acknowledgment

The study upon which this paper was founded was made possible by the generous participation of the many talented and busy educational technology leaders in Western Canada who took time out of their schedules to participate in this comprehensive research. Formal teaching and learning activities around the world are often and increasingly facilitated through the use of technology. The work of educational technology leaders and practitioners K-12 is an essential, though sometimes overlooked aspect of contemporary education. To these men and women, much credit is due.

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