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The Growth of Computer Science Education in Alberta: An Analysis of High School Course Completion Trends

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Computer Science (CS) education is an emergent growth area in schools worldwide. This paper explores how CS education has evolved at the high school level (grades 10–12) in the Canadian province of Alberta over the past decade after a reorganization and curriculum redesign of its Computing Science Education (CSE) program. In partnership with Alberta Education, a complete list of course records was obtained for high school students who had taken CSE course credits between 2009 and 2019. These course completions were analyzed for overall growth trends and then further examined with respect to course level, urbanicity, and gender. We found that growth in course credit completion has been consistent over the 10-year study period (annual average growth rate of 33.5%). Advanced course credits have grown faster than introductory course credits, urban areas have grown faster than rural areas, and gender growth rates have been similar for males and females. Understanding the growth rates of CSE course enrollments at the high school level will contribute to identifying some of the challenges encountered during the implementation of the CSE program of studies in Alberta.

L'enseignement de l'informatique est un domaine de croissance émergent dans les écoles du monde entier. Cet article explore l'évolution de l'enseignement de l'informatique au niveau secondaire (10e à 12e année) dans la province canadienne de l'Alberta au cours de la dernière décennie, après une réorganisation et une refonte du programme d'études de l'informatique. En partenariat avec le ministère de l'éducation de l'Alberta, on a obtenu une liste complète des dossiers de cours pour les élèves du secondaire qui ont reçu des crédits pour des cours d'informatique entre 2009 et 2019. Ces cours ont été analysés pour déterminer les tendances générales de croissance, puis examinés plus en détail en fonction du niveau de cours, de l'urbanité et du sexe. Nous avons constaté que la croissance de l'obtention de crédits de cours a été constante au cours de la période d'étude de 10 ans (taux de croissance annuel moyen de 33,5 %). Les crédits de cours avancés ont augmenté plus rapidement que les crédits de cours d'introduction, les zones urbaines ont augmenté plus rapidement que les zones rurales, et les taux de croissance ont été similaires pour les hommes et les femmes. La compréhension des taux de croissance des inscriptions aux cours d'informatique au niveau secondaire contribuera à identifier certains des défis rencontrés lors de la mise en œuvre du programme d'études en informatique en Alberta.

The ongoing digital revolution has encouraged the rapid integration of technology into schools, the workplace, and our daily lives. Outside the recognizable disciplines of computer science and software engineering, sought-after areas like artificial intelligence, robotics, and machine learning dominate the news cycle and job posting boards across multiple career pathways. In this article, we explored the growth of computer science education (CSE) in high schools (grades 10–12) in the province of Alberta, Canada between 2009–2019 in the decade preceding the COVID-19 pandemic. Alberta is one of 13 provinces and territories in Canada and currently serves over 740,000 K–12 students in its publicly funded educational system (Government of Alberta, 2022). The high school Career Technology Studies (CTS) program of studies includes a comprehensive set of computer science (CS) courses and outcomes that are used by teachers in the province of Alberta (Alberta Education, 2009b).

For this project, we examined the records of over 36,000 Albertan students enrolled in high school CS courses during 2009–2019. The analysis focused on the longitudinal enrollment patterns/trends relative to differences across grade levels, retention rates across grade levels, urban and rural school districts, and gender participation. Our findings provide an overview of the Alberta high school CSE landscape and contribute patterns and evidence that can inform future CSE curriculum development and implementation throughout the Alberta K–12 program of studies.

Background

Computer Science (CS) is a young academic discipline compared to its Science Technology, Engineering, and Mathematics (STEM) counterparts. At the University of Alberta, for example, the first programming course was offered in 1960; by 1964, the university had established the first Department of Computing Science in Canada (University of Alberta Alumni Association, 1993). Today, CS is a well-established field of study taught in universities around the globe.

However, up until recently, the uptake of CS as a subject area in secondary and primary schools had been slow and sporadic (Gal-Ezer & Stephenson, 2014; Webb et al., 2017). With a few exceptions like Poland and Israel (Benaya et al., 2017; Heintz et al., 2016), CSE did not begin to appear in national and state school curricula until the late 1990s. Even so, adoption has lagged considerably, with CSE in schools spreading across the globe at very different rates (Denning & Tedre, 2019).

CS K–12 Education Movement

Over the last decade, interest in CS education “for all” has begun to surge, spurred by a number of possible factors: a lack of skilled CS workforce compared to market demand globally (Bottoms & Sundell, 2016), an increasing public perception of CS as a fundamental skillset (Vakil, 2018), and climbing post-secondary CS enrollment numbers (Zweben & Bizot, 2021). It has become increasingly clear that schools need to keep pace by providing students with a solid foundational knowledge base in the area of computer science (Heintz et al., 2016; Passey, 2017; Webb et al., 2017).

Following the “dot.com bust”, there was a dip in CS college enrolments in the early 2000s (Zweben & Bizot, 2021). Although post-secondary CS enrolments have since recovered, the downturn led to a series of critical introspective reports on the status of the CSE: *Running on Empty* (Wilson et al., 2010), *Shut Down or Restart* (Royal Society, 2012), and *Europe Cannot Afford to Miss the Boat* (Gove, 2013). These reports highlighted several key questions regarding the implementation of CS education in schools, including examining the purpose of CSE programs, when CSE should begin, what its core competencies should be, and how this implementation should be realized with respect to CSE policy and teacher training (Gove, 2013; Royal Society, 2012; Wilson et al., 2010). Further research studies and literature reviews regarding the implementation of K–12 CSE drew similar conclusions (Battal et al., 2021; Benaya et al., 2017; Fluck et al., 2016; Hubwieser et al., 2014, 2015; Lye & Koh, 2014; Webb et al., 2017). Today, CSE is seen as a core aspect of digital literacy for school aged students; exposure to CS throughout their elementary and secondary education helps prepare students for the digital world and allows for CS as a future career or post-secondary option (Barr & Stephenson, 2011; Li et al., 2020; Wing, 2008; Yadav, Good, et al., 2017).

In response to the Royal Society report (2012), the UK restructured its national curriculum in 2012 to include CS as a mandatory component of primary and secondary school programs. Countries such as Israel and Russia have responded to the K–12 CSE movement by amplifying the stature of their existing programs and integrating CS learning into the curriculum at an earlier age (Armoni & Gal-Ezer, 2014; Hubwieser et al., 2014; Khenner & Semakin, 2014). France and New Zealand chose to redesign CSE from the ground up (Baron et al., 2014; Bell, 2014).

CS K–12 Education in North America

Adoption of a K–12 CS curriculum has proceeded at varying rates in educational constituencies across North America. In both the United States (US) and Canada, K–12 curriculum is decided at the state and provincial level respectively. Nonetheless, top-down federal government initiatives like "Computer Science for All" (Smith, 2016) have provided some guidance and inspiration for CSE program development (Vakil, 2018; Vogel et al., 2017). CSE curriculum development has also been guided by the Computer Science Teachers' Association (CSTA, 2017), another critical non-profit professional organization. The CSTA publishes curriculum outcomes for K–12 CSE that serve as a framework for state curriculum organizations as well as a guide for CS teacher education and professional development (Guo & Ottenbreit-Leftwich, 2020; Rosato et al., 2021; Seehorn & Clayborn, 2017). The CSTA curriculum is intended as a guiding resource for other jurisdictions to apply in their own curriculum development. According to Guo and Ottenbreit-Leftwich (2020), 22 of the 34 current states with published CSE curricula use the CSTA framework extensively in the development of their learning outcomes. For example, the California Department of Education and the New York State Education Department have both recently legislated an extensive new CS curriculum from K–12 that incorporates many of the CSTA standards (California Department of Education, 2017; New York State Education Department, 2020).

In Canada, federal government funding initiatives like CanCode have been offered to encourage the development of coding camps for children, teacher education workshops, and regional programming initiatives (Government of Canada, 2018). Canada Learning Code (CLC), one of the multiple Canadian non-profit organizations funded via CanCode, commissioned the development of a pan-Canadian CSE framework to help guide curricular development at the provincial level (Canada Learning Code, 2020). However, because curriculum is legislated at the provincial level, the CLC framework serves much the same guidance-only purpose as the CSTA K–12 CS Standards in the United States.

CLC's (2020) *Learning for the Digital World: A Pan-Canadian K–12 Computer Science Education Framework* explores the current state of CSE in Canada, identifies guiding values behind CSE development, and suggests curricular outcomes for all levels of learning. Despite the fact that 90% of education stakeholders surveyed by CLC believe students should be learning about CS in elementary and middle school, only 7/13 Canadian education authorities currently have any CS outcomes in their pre-high school curriculum, and further, most of these outcomes have only recently been added (Canada Learning Code, 2020).

Nova Scotia was the first to adopt a mandatory CSE curriculum at the elementary level in 2017 (Julie, 2017). The provinces of British Columbia (Province of British Columbia, 2018) and Ontario (Ontario Board of Education, 2020) adopted K–12 CS curricular outcomes in 2018 and 2020 respectively. The British Columbia curriculum focused on expanding professional development and encouraging enrollment in female and indigenous students (Fowler et al., 2021). Ontario has integrated elementary school CS into its mathematics curriculum and emphasized an increased need for professional development funding and opportunities (R. Barnes, 2020; Davidson, 2022; Ontario Board of Education, 2020). Other provinces have focused on the expansion of CSE at specific school ages: Nova Scotia focused on developing K-6 CSE while New Brunswick has targeted the middle school grades (Julie, 2017).

CS High School Education

CSE high school programs existed well before the 2010s push for K–12 CSE. Gal-Ezer and Stephenson (2014) noted that Israel, a geographically small country with a more centralized curriculum, has offered an academic CSE program since the mid-1970s. Bell (2014) described a similar situation in New Zealand, another small country with a centralized curriculum that has had CS in high school since the mid-1970s. Bell added that New Zealand underwent a CSE program review in the early 2010s and moved to change CSE curriculum from a programming-centered curriculum towards a more in-depth computational thinking approach to CSE. Similar shifts in CSE occurred in Israel (Gal-Ezer & Stephenson, 2014), Poland (Sysło & Kwiatkowska, 2015), Estonia (Heintz et al., 2016), and South Korea (Choi et al., 2015). Smaller countries with national curriculum control have been able to make this curriculum shift and adjust their CSE programs faster than Canada or the United States.

There is a deep, rich history of CSE in North America, but localized to the jurisdictions that have made it a priority. The existence of isolated CSE programs in high schools, however, is different from nationwide initiatives like CS for All (2016) and CanCode (2018) that began the push for K–12 CSE programming in the mid 2010s in North America. CSE high school programs in North America have varied widely in their reach and curriculum as regional or even district control over curriculum decisions make generalizations about North American CSE difficult (Gal-Ezer & Stephenson, 2014). In Canada, Floyd (2019) noted that Ontario has had programming courses offered since 1966 and a CSE curriculum since 1970, but is silent on CSE high school programs in Canada's other provinces and territories. In California, a 2005 review of all computer courses in high schools revealed that only Advanced Placement computer science (APCS) taught any theoretical CS topics (Goode, 2007). Though APCS and its corresponding AP examination had been in place since 1984, access to CSE was limited to high achievers and focused on very specific topics like Java programming (Goode, 2007). Prior to the mid-2010s K–12 CSE and the "CS for All" movement, less than half of Californian students attended a school with access to CS course offerings (Bruno & Lewis, 2021, 2022).

CS High School Education in Alberta

CSE was formally introduced to Alberta's provincially authorized high school curriculum in 1997 as part of the Career and Technology Studies (CTS) program.[1] CTS is an elective program that covers a wide range of career pathways; it consists of one-credit courses that can be bundled together to adapt to student interests and future workplace needs (Alberta Education, 2009a). The CTS curriculum was substantively revised in 2009, reflecting pressures from various stakeholders and the changing employment landscape. Today, the CTS curriculum is comprised of five clusters—Business, Administration, Finance & Information Technology (BIT); Health, Recreation & Human Services (HRH); Media, Design & Communication Arts (MDC); Natural Resources (NAT); and Trades, Manufacturing & Transportation (TMT) (Alberta Education, 2009b). Each cluster is further divided into occupational areas. Computing Science Education (CSE) is one of several occupational areas belonging to the BIT cluster.

The occupational areas consist of sets of one-credit courses organized according to three skill levels: 1000-level introductory, 2000-level intermediate, and 3000-level advanced (Alberta Education, 2009b). The one-credit CTS courses are typically packaged together by teachers, usually in three, four, or five credit bundles mindful of prerequisites, and offered to high school students as elective courses. For example, "Computer Science 10" may consist of five CSE 1000-level courses such as CSE 1010: Computer Science 1; CSE 1110: Structure Programming 1; CSE 1120: Structure Programming 2; CSE 1240: Robotics Programming 1; and CSE1910: CSE Project A. Although the one-credit components are called "courses" in the Alberta Education CTS Program of Studies, we will refer to them here as "modules." We hope this terminology will help avoid confusion between a computer science course—typically worth three to five credits—and the one-credit Alberta Education courses (now "modules") that comprise it.

Altogether, the CSE occupational area of the curriculum lists 32 modules (one-credit courses) across three skill levels that cover a range of CS proficiencies (Alberta Education, 2009b). There are also one-credit modules in other CTS clusters that are related to CS and may be used by teachers as part of a CS course bundle. For example, an Electro-Technologies or ELT 1000-level module may be bundled with CSE 1000-level modules and listed as "Computer Science 10". Choice of the one-credit modules may also depend on the teacher expertise and resource availability at a school. For this reason, there may be some disparity in the CS curriculum outcomes a student will encounter across different school institutions offering CS courses; in contrast to other science curricula (Biology, Chemistry, Physics) where the programs of study are standardized and formally assessed in a uniform manner throughout the province.

After the mid-2000s recession and dot-com bubble burst, CS in Alberta faced a parallel situation to that presented in the UK report (Royal Society, 2012)—enrollment in postsecondary institutions was stagnating and the program needed an update (Hoover, 2011). When Alberta's CTS program of studies was updated in 2009, the Department of Computing Science, University of Alberta formally added "Computing Science (CSE) Advanced Level-Career and Technology Studies (CTS) (5 credits)" as one of its Group C (Maths/Science) high school admission courses in the Faculty of Science (Hoover, 2011; University of Alberta, n.d.-a). Following that significant university entrance change, Grade 12 level CS was quickly added as an admissible science subject for entry at the University of Calgary and other post-secondary institutions around the province. Finally, it is important to reiterate that CSE continues to be an elective offering in Alberta high schools; it is not included as a separate subject in the high school science or mathematics curricula (Hoover, 2011).

Recent discussion in Alberta has focused on the development and implementation of elementary CSE (Adams et al., 2021; French, 2018). Though Alberta has been a Canadian CSE pioneer in high school, it has not yet been formally implemented for younger students. Two recent cross-curriculum redrafts have included CS elementary school outcomes in elementary education, however, neither rewrite has been formally adopted into law. The first curriculum draft included comprehensive CSE outcomes in both the K–4 mathematics and science curricula (Alberta Education, 2018); the subsequent curriculum draft integrated explicit CSE outcomes into the K–6 science curriculum (Adams et al., 2021; Alberta Education, 2022a). Both curriculum drafts mirror many of the newer CSE models focusing on the early development of CS skills and the introduction of formal programming concepts over time (Alberta Education, 2022a). Learning in elementary education intends to emphasize the importance of computational problem-solving and digital citizenship; the latest draft has benefited from the Canada Learning Code curriculum framework to guide its development along with several other key CSE K–12 documents (Adams et al., 2021; K. Barnes, 2020).

Literature Review

In the following section, we outline three key research areas: growth and retention of students in CS high school courses, gender equity in CSE; and the occurrence of CSE in urban vs rural high schools. Examination of CSE HS growth rates and retention is relevant in positioning our study both nationally and internationally. Gender and urbanicity literature serve the same purpose for the independent accessory variables; examining the history, prevalence, and persistence of equity issues in CSE with respect to gender and urbanicity lend credence to the discussion surrounding these topics in our local Albertan perspective.

CSE HS Program Growth and Retention

Measuring growth and retention of high school CS courses is critical in tracking student enrollment and program success. However, to-date, only a handful of such studies have been conducted. Prior to 2021, studies of CSE in high school were primarily descriptive (Bell, 2014; Hubwieser et al., 2015; Webb et al., 2017) and/or lacked clarity regarding whether the topics were in fact CSE or basic computer literacy (Allan et al., 2010; Goode, 2007; Margolis et al., 2003). In these examples, authors described the process of CSE adaptation in schools or in top-down governmental approach, but didn't contain empirical student data (enrollment numbers, course completion percentages, or otherwise). To situate our study appropriately, we require numerical growth data on in-situ student CSE populations at the high school level.

Two recent empirical studies have provided some clarity on the growth of CSE in high schools via an analysis of year-on-year enrollment patterns (Bruno & Lewis, 2022; Floyd, 2021) and as a percentage of total course enrollment (Bruno & Lewis, 2022). Floyd (2021) used enrollment data in Ontario high schools and expected grade-level participation in five CS courses as a metric to estimate CSE participation. Floyd analyzed growth over a ten-year period for male and female students and concluded that there was equal growth in CSE participation for both genders (2021). Bruno & Lewis (2022) presented a similar study done in California high schools, using CS enrollment as a percentage of total course enrollments to estimate levels of student participation while at the same time controlling for student population growth. They showed a near fourfold increase in CSE participation, illustrated by an increase from 0.24% of all course enrollments in 2003 up to 0.82% of enrollments in 2018 (Bruno & Lewis, 2022). Bruno and Lewis also analyzed access to CSE as a variable, noting that 45.2% of students attended a high school offering CSE in 2003 compared to 79.1% in 2018.

Gender Equity and CSE in High School

Gender equity in the computer science classroom has been primarily researched at the undergraduate level. Two things are immediately evident in the postsecondary literature: a) the gender gap in CSE is not new (Hayes, 2010; Sax et al., 2017; Schubert, 1986) and b) despite attempts to address the gender gap, most efforts have not improved CSE gender equity (Baer & DeOrio, 2020; Hayes, 2010; Sax et al., 2017; Zagami et al., 2015). Though the existence of a CS gender gap has been consistent since the early days of CS undergraduate programs (Hayes, 2010; Papastergiou, 2008; Sax et al., 2017), the degree of gender inequity has fluctuated over the last 50 years (Sax et al., 2017). Sax et al. (2017) noted that amongst American post-secondary CS graduates, female participation fluctuated from a low of 13% (1971) to a high 37% (1985), and was recently sitting at 18% (2014). The most up-to-date literature suggests that some gains have been made since the mid-2010s, though progress has been slow and will not soon result in gender equity (Baer & DeOrio, 2020; Jaccheri et al., 2020; West et al., 2019).

Hayes (2010) noted that the decline in CSE participation is especially confounding as female representation in other STEM areas has grown rapidly over the same period—often in traditionally male fields with similar extant male work culture and leadership. Ching et al. (2021) noted that within math-intensive Canadian undergraduate STEM areas, CSE programs show a larger gender gap than math, physics, or chemistry. Gender inequity in some STEM areas has diminished greatly as access to STEM has been encouraged in earlier education (Caspi et al., 2019; Sax et al., 2017). A Caspi et al. (2019) study examining STEM majors for Israeli high school students noted that although gender did not play a role in whether STEM areas majors were chosen overall, it did dictate which STEM areas are chosen, with physics and CSE underrepresented for females.

In high school, female CSE participation trends have been tracked as similar to those in post-secondary education. Floyd (2021) analyzed CSE course participation rates in five Canadian Ontario high school CSE courses using a multi-year dataset. He found that female course completion comprised 21.5% of all students in its most recent year of data (the 2017-18 school year). Floyd's course data showed that despite overall program growth, female participation between 2009 and 2018 remained consistent, ranging between 17.2% and 21.5%. In California, Bruno and Lewis (2021) measured gender with respect to CSE access and to CSE enrollments as a percentage of overall courseload. They concluded that female students in California high schools had equal access to CSE and that although both gender groups grew exponentially in their CSE coursework percentages (females from 0.01% to 0.08% and males from 0.06% to 0.18%), the gender gap in the CS classroom remained. Research by Hazzan et al. (2019) in Israel reported that 32% of high school CSE students are female; higher than in Ontario or California, but still a notable gender gap for a country with a long history of CS high school curriculum (Armoni & Gal-Ezer, 2014).

The Advanced Placement (AP) College Board (2023), responsible for administering AP exams to high school students, reported that only 20% of students in 2012, 27% in 2017, and 30% in 2021 who wrote CS exams (CS A and CS Principles) were female. Stephenson and Dovi (2013) noted that for the 2012 AP exam year, 20% female participation in CSE was low compared to 55% female participation across all AP exams. Bruno and Lewis (2022) offered an updated figure from 2018, with female-identifying students writing 55% of all exams, but only 28% of CS exams. In the UK, the Royal Society (2017) reported similar numbers on British high school GCSE exams and

Scottish National 5 exams, with 20% of CS exams written by females in both instances (Royal Society, 2017).

Reasons for the CSE gender gap have been hypothesized for decades. Schubert's (1986) text hypothesized many of the same gender gap drivers that are mirrored in contemporary CSE discussions today—a lack of positive role models (Cheryan et al., 2015; Gisler et al., 2018; Margolis & Fisher, 2002; Zagami et al., 2015), reduced availability of resources for female students (Butterfield & Crews, 2020; Main & Schimpf, 2017; Miliszewska et al., 2006), and preconceived notions of what it is to be a computer scientist (Cheryan et al., 2015; Gretter et al., 2019; Milesi et al., 2017; Sax et al., 2017). Margolis and Fisher (2002) suggested various reasons why participation in CSE has resisted gender equity, arguing that curriculum, culture, and male-gendered role models throughout formal school promote the idea that computing is a male activity. In *Stuck in the Shallow End*, Margolis (2017, pg.74) again emphasized the ongoing "white male" participant stereotype as a major driver of race and gender equity issues in CSE. Gisler et al. (2018) noted that the retention of females in CSE may also be a major issue in gender equity. Vakil (2018) argued "that a more serious engagement with critical traditions in education research is necessary to achieve a justice-centered approach to equity in CS education … to address concerns around expanding access to girls and historically underrepresented students of color" (p. 1).

CS in Rural Education

A national poll reported that only 10% of American high schools that offer CSE are rural, even though rural and small town schools make up 42% of schools overall (Google LLC & Gallup Inc, 2017). The Royal Society (2017) noted a similar discrepancy in the UK, reporting that despite 70% of the student population attending a school offering CS courses, these mainly represented schools in large urban centers. A study in Maryland found 28.6% of rural schools offered no CS courses while that was only true in 6.3% of urban and 2.1% of suburban schools (Desjardins & Martin, 2013). Surveying an American participant pool, Gallup and Google (2020) found that school principals in rural, town, suburban, and city schools (Range 77–85%) all recognized the significance of CSE in improving their students career options. Students from rural schools were the least likely to have learned CS concepts (45%) compared to towns (56%), suburbs (61%), and cities (62%).

Warner et al. (2019) cited difficulty in attracting qualified CS teachers as the major driver for this deficit. Difficulty in hiring CS-qualified staff aligns with earlier predictions (Royal Society, 2012; Yadav, Gretter, et al., 2017) that foresaw a lack of qualifying teaching staff as a major barrier to CSE growth. Some authors (Kryst et al., 2015; Upadhyaya et al., 2020) suggested that despite technological advances, the rural disadvantage in CSE and STEM in general may be growing. Identifying and addressing the rural gap in CSE is critical in establishing educational equality and opportunity for all students (Kryst et al., 2015; Qazi et al., 2020).

Methods

CS course information, student course credit completions, and school authority data were obtained in line with ethics protocol via a partnership with the Alberta Learning branch of the Government of Alberta. All student data were anonymized; a secure CSV file was shared, downloaded and stored on a single device for the purposes of data manipulation and analysis, and was backed up to a secure drive. Due to the large data set (1.56 million rows of data), we decided to use R Studio (R Core Team, 2013) for data organization, cleaning, and exploratory analysis. Additional R packages including *dplyr* (Wickham et al. 2021), *janitor* (Firke 2021), and *ggplot2* (Wickham, 2016) were installed to support the analysis in this project. Supporting documentation including provincial school authority data, district student population estimates, and CSE module summaries were all obtained directly through the Alberta Education website (Alberta Education, 2009b).

Alberta Education provided the course credit completion records of all students that had completed a CSE module credit in Alberta from 2009/10 through the 2018/19 school year. Subset sampling methods were not required because we were able to access the entire database of CSE course participation since its inception in the 2009/10 school year. This included all CSE credits completed and linked to unique Alberta student ID numbers. Along with ID number and school year, critical variables included gender, school authority, and CSE module course code. Incomplete data rows were eliminated from the data set. As these data were drawn from a standardized government database, this data loss was minimal (~0.2%). Initial descriptive statistics were gathered at this point both as a reference point to inform further piecewise analysis.

Gender was evaluated as a binary statistic in this research because that is how the Alberta Education dataset has gender stored and recorded. There is now an additional gender option "x" but as it has only existed from 2015/16 forward (and its sample size is very small), analysis of this subset was not possible. An additional variable was also created to allow for the investigation of the urban-rural relationship to CSE. As we were not permitted access to school names and/or locations, this was done at the school authority level. Of the 378 school authorities in Alberta, 92 were represented in the dataset. These include public, private, and charter schools as all schools are required to submit their course completion data to Alberta Learning and were therefore included in our dataset. A large number of unrepresented school authorities was expected as many authorities are very small or represent schooling environments for early education or specialized education settings that do not typically include CSE. Cross-referencing our data in R with a provincial school authority database (Alberta Education, 2022b) allowed us to code our data into four categories: urban, suburban, small urban, and rural. Urban school authorities were those located in the municipalities of Edmonton and Calgary (populations greater than one million). A suburban distinction was created to represent school authorities that are not in Edmonton or Calgary but are located within close proximity (commuting distance) from the two major Alberta cities. Small urban authorities represent cities that are not commutable from major cities but are relatively large (population > 30,000). Rural authorities are the catchall for the remaining school authorities in the province. This includes some smaller municipalities and towns whose authorities also include large swaths of surrounding rural areas—though these were generally low population.

Data subdivisions were created using the *tabyl* R function contained in the janitor package. This function allows for two and three-dimensional data tables to be generated. For these, year was used as the independent variable (listed first in the tabyl function) as our primary focus was evaluating CSE trends over time. Two-dimensional tabyl functions were first generated for gender, school authorities, and CSE module course codes. Additionally, we focused on these relationships by generating independent data slices for 1xxx, 2xxx, and 3xxx level CSE courses, and then repeated the tabyl generation for course codes, gender, and school authority. These tables allowed us to evaluate the broad spectrum of CSE trends across the province of Alberta over the past ten-plus years.

Because the primary objective of this project is an exploratory overview of Alberta CSE, the statistics used for this paper are descriptive. Regardless of the individual variables studied, CSE completion count was the targeted dependent variable. Frequency counts of CSE module completions make up a large amount of our analysis. Cross tabulations of each variable were examined to determine relative rates of module completion with respect to the school year. CSE growth rates were evaluated independently with respect to the population increase of their individual school districts over time using simple linear regression. Although our data were robust and our sample size large, program growth rates (as measured by module completions) were determined to be the most user-friendly method of data analysis so we focused on enumerating the growth rates of each variable group with respect to the overall CS program growth.

Results

Initial statistical observations were used as a guide for the remainder of our exploratory data analysis. As trends and oddities in the dataset became apparent, we followed those clues in an effort to better understand the current state of CSE and where future research may be best directed. For descriptive statistics, we used a baseline dataset with n = 197,721. This "n" corresponds to the number of CSE completions in the province of Alberta for the period from 2009 until 2020. Module completions from the 2019/20 school year were excluded from further analysis (n = 11,718) to eliminate statistical anomaly due to incomplete reporting at the time of data collection and as a result of school course cancellations from the COVID-19 pandemic. This left us with data running from 2009/10 to 2018/19 (10 school years) and a CSE module completion n = 185,803.

Baseline CSE Growth

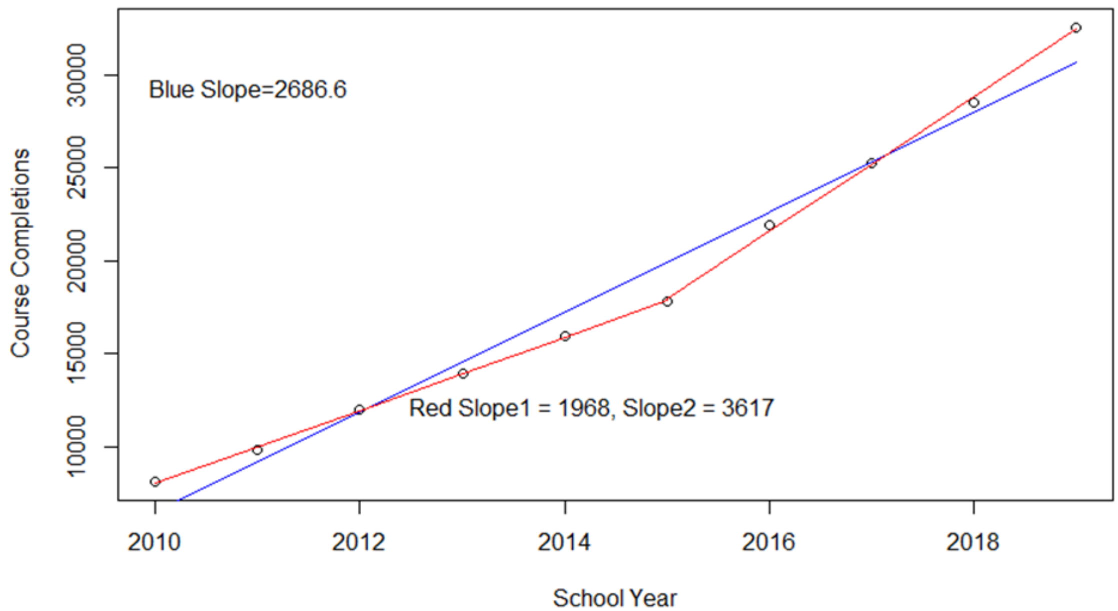
First, we calculated the overall growth rate of CSE since the introduction of its new naming in the 2009/10 school year (first year n_{min} = 8107). CSE module completion has grown every year since its inception and reached a maximum in the most recent year of complete data (2019, n_{max} = 32560). CSE growth has progressed in a steady linear pattern (Figure 1, m = 2687) across the province, averaging a linear growth rate of 33.5% per year. Though the sample size is small, we could also split the growth trend graph into a piecewise function around the 2015 datapoint to reveal two different growth slopes (Figure 1, m_1 = 1968, m_2 = 3617). General student population data were also evaluated and high school growth rates have been low for the duration of the study timeline (0.64% annual increase, Government of Alberta, n.d.,).

CSE Module Level (1XXX, 2XXX, 3XXX)

CSE module completions occurred across all 32 unique module course codes, ranging from a minimum of 15 (CSE 2950—CSE Intermediate Practicum) to a maximum of 33,600 (CSE 1110—Structured Programming 1; Alberta Education, 2009b). Module completions can be further analyzed by exploring the breakdown between 1000 level, 2000 level, and 3000 level modules. Though 2000 and 3000 level higher level course modules are not necessarily dependent on 1000 level course prerequisites, this is often the case. For example, CSE2010 (Computer Science 2) lists CSE1010 (Computer Science 1) and CSE1120 (Structured Programming 2) as prerequisite course modules. There are higher order course modules (the project-based course CSE2910, for example)

Figure 1

CS Course Completions by Year



Note. Module completion data is laid out by year, graphed by linear regression line (blue) and piecewise into two linear subfunctions (red).

that don't have prerequisite courses, but these often have 1000-level analogies that would likely be taken in their place at the introductory level. All course level areas had positive growth rates over the study period, with higher-level modules growing at a faster rate per annum than 1000 level modules (1000 level—27.09%. 2000 level—40.65%, 3000 level—66.58%). The overall growth rate of 33.5% is weighted heavily towards 1000 level modules due to their large relative "n" to higher-level modules. Cumulative growth over the study time period shows this increase clearly (Figure 2, 1000 level—243%, 2000 level—366%, 3000 level—599%).

Urban/Rural Breakdown

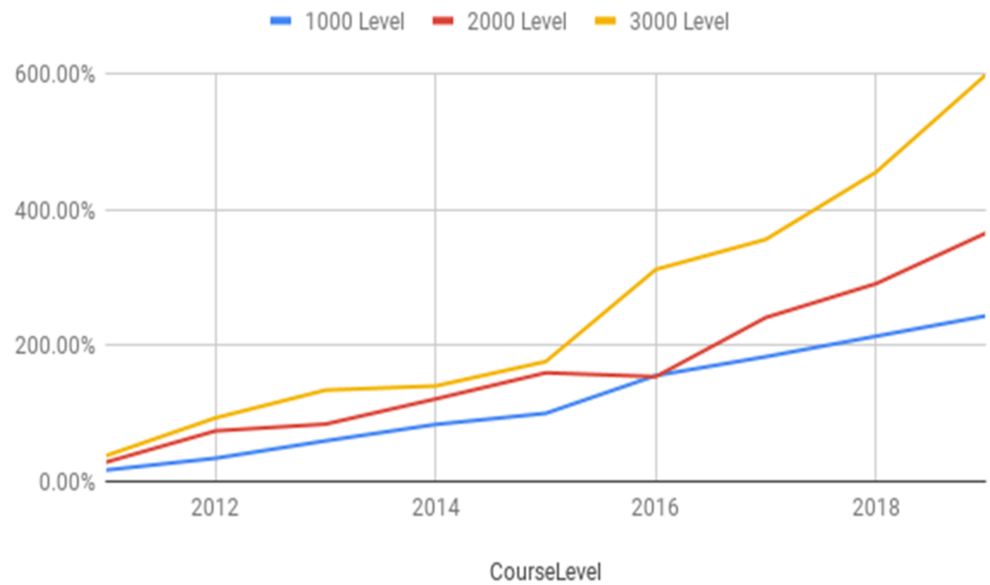
Urbanicity was split into four unique groups: urban, suburban, small urban, and rural. Analysis for these groups is challenging due to the vastly different sizes of the sampled populations. Since the onset of new CSE curriculum implementation across the province, all four groups have again experienced growth. The rural group experienced the lowest cumulative growth (up 98%) while the urban and suburban groups increased similarly (urban = 310%, suburban = 332%). The small urban group had by far the most dramatic cumulative growth at 603% (Figure 3).

Gender Analysis

CSE is growing in both male (m = 2275 module completions/year) and female (m = 409 module completions/year) cohorts (Figure 4). Overall, male students account for the vast majority of CSE module completions (n_{male} = 160,520 (86.4%), n_{female} = 25,223 (13.5%). The uptake rate for male students is higher than that for female students and the cumulative growth rate runs nearly in parallel. CSE module completions have increased by 300% for the male population since inception while female module completions have increased by 312%.

Figure 2

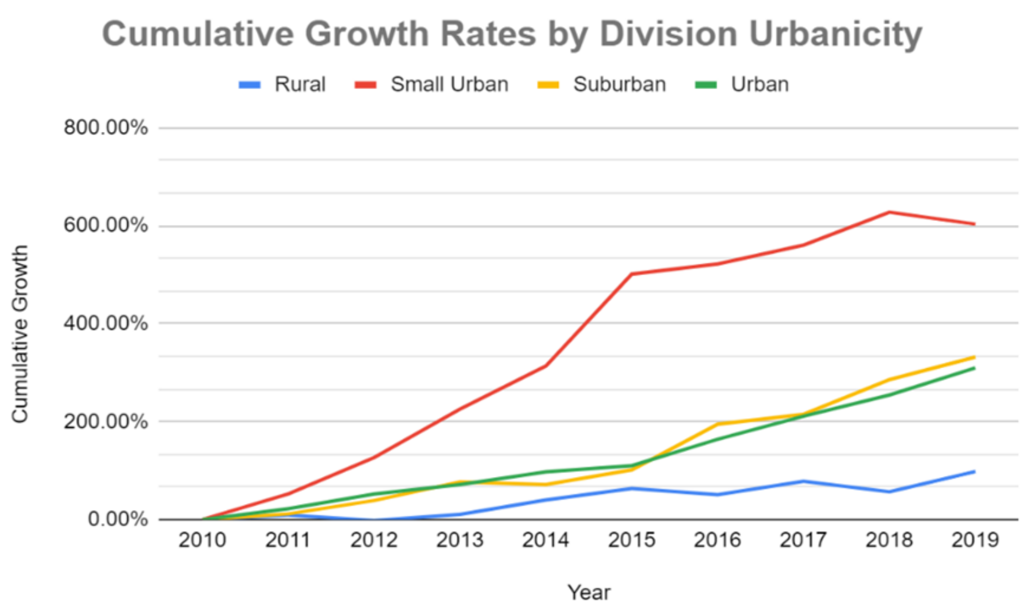
Cumulative Growth Rates by Course Level



Note. This figure shows the cumulative growth rate of 1000/2000/3000 level module completions. These are roughly representative of grade 10, grade 11, and grade 12 completion, though course levels can be mismatched and offered in the same grade/course offering.

Figure 3

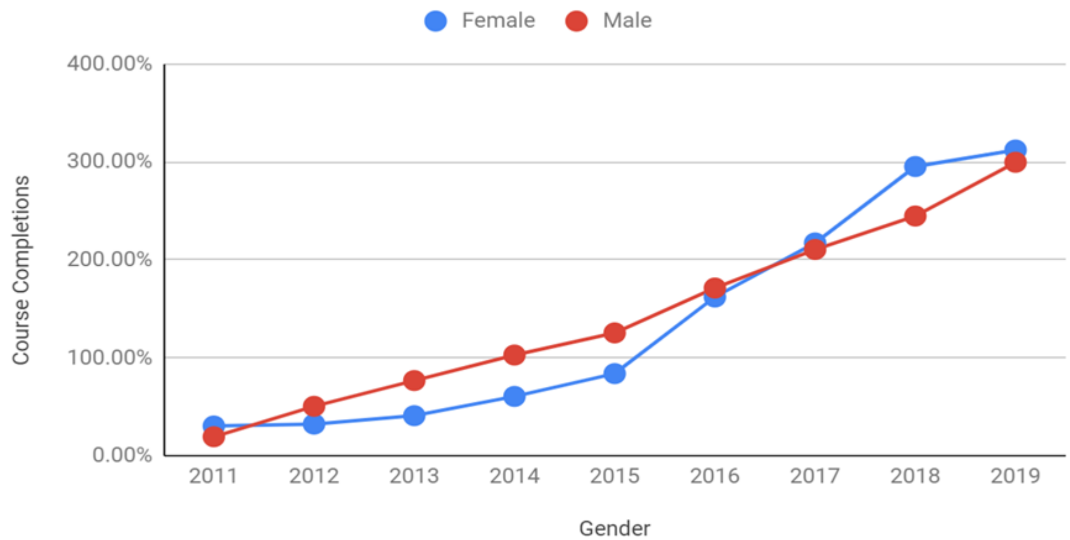
Cumulative Growth Rates by Division Urbanicity



Note. Cumulative growth rates for school authorities since CSE inception in 2009. Urban groups were determined based on city sizes within the division and proximity to large urban centers (Edmonton and Calgary).

Figure 4

Cumulative Growth Rates by Gender



Note. Cumulative growth rates in male and female students since CSE inception in 2009. Non-binary gender variables were not available for the duration of the study data and were therefore not included in the analysis.

Gender vs Module Level

Gender module completions can also be examined at successive course levels. As seen in Table 1, progression of students in all levels of CSE have increased since its inception in 2009-10. In both genders, this has included an increase in the proportion of module credits completed in more advanced modules (2000 and 3000 level CSE credits). For females, 3000 level credits made up only 2.9% of all female module completions in 2009-2010. In 2018-19, this percentage was 12.7%.

An alternative way to visualize this information was to examine the level of CSE student retention from year to year. This was estimated by phase-shifting the yearly completion data to explore which students completing CSE 1000 credits completed 2000 level credits the following year and so on. In Figure 5, we can see the change in student retention by gender from 1000 to 2000 level as represented by their slope (male m = -0.02x, female m = 0.92x). Figure 6 displays the change in student retention from 2000 to 3000 level (male m = 2.21x, female m = 3.83x).

Gender vs Urbanicity

Gender was also analyzed through the lens of urbanicity (Table 2). Average rates of growth here are notably different in different urban areas in the province. Rural female numbers have stayed stagnant (average growth rate = 0.65%) compared to males (average growth rate = 15.37%). In small urban centres, the trend is opposite with females showing tremendous growth (average growth rate = 91.32%) compared to males (average growth rate = 64.25%). Suburban and urban rates were also different, though much more tightly grouped.

Table 1

Percentage of Students by Gender in Different Course Levels

Year	1000 Level		2000 Level		3000 Level	
	Male	Female	Male	Female	Male	Female
2010	67.99%	83.88%	21.81%	13.20%	10.20%	2.92%
2011	66.15%	76.48%	22.53%	17.95%	11.32%	5.57%
2012	62.39%	72.61%	25.21%	17.95%	12.40%	9.44%
2013	64.15%	74.34%	22.65%	18.11%	13.20%	7.55%
2014	64.35%	75.22%	23.93%	17.38%	11.72%	7.40%
2015	62.74%	73.73%	25.28%	17.73%	11.97%	8.53%
2016	64.73%	78.16%	20.26%	14.03%	15.01%	7.81%
2017	62.95%	69.87%	23.13%	19.35%	13.92%	10.78%
2018	61.37%	69.07%	23.56%	19.39%	15.06%	11.54%
2019	59.08%	66.21%	24.39%	21.04%	16.53%	12.75%

Note. Module completions by gender by difficulty level (as a percentage of total completions across all grade levels for that gender)

Table 2

Annual Growth Rate Averages by Gender

Urbanicity	Growth Rates		Total Average Growth
	Females	Males	
Rural	0.65%	15.37%	10.91%
Small Urban	91.32%	64.25%	67.02%
Suburban	23.27%	38.94%	36.88%
Urban	46.49%	32.73%	34.39%

Note. Average annual CS module completion growth rates by urbanicity, split to show gender differences in different urbanicity cohorts

Module Level Vs Urbanicity

Module Level was also evaluated via urbanicity (Table 3). Total average growth rates were swayed heavily by urban group data as the sample size from this group was much larger than others. The small urban cohort saw large, consistent growth across all module levels. Suburban and urban groups saw increased growth in more advanced module level areas, with the suburban trend more pronounced than that of the urban. Rural annual growth rates were lower at all module levels.

Discussion

Computer science as a whole in Alberta has grown at a remarkable rate (33.5% annual average growth rate) since the curriculum changes were made to the CTS program of studies in 2009/10. This growth rate is even more pronounced when compared to the overall high school student

Table 3

Annual CS Completion Rates in Urban Groupings by Course Level

Course Level	Urbanicity				Total
	Rural	Small Urban	Suburban	Urban	
1000 Level	11.30%	68.14%	25.34%	27.85%	27.09%
2000 Level	6.52%	62.56%	81.98%	38.38%	40.65%
3000 Level	17.24%	68.42%	148.15%	65.00%	66.58%

Note. Average annual CS completion growth rates by urbanicity, split by module level to show module level differences across urbanicity groupings

population (0.64% annual growth). We do not have total course completions per year to compare to as given in the Bruno and Lewis (2022) study in California. But comparing the stagnant high school population annual growth rate (0.64%) to CSE course completion growth rate, the magnitude of difference suggests CSE is a rapidly growing program. Similar to Bruno and Lewis (2022), Alberta's CS course completion grew fourfold (n = 32,533 completions in 2018/19 vs n = 8107 completions in 2009/10), although in Alberta this growth occurred over a shorter timeframe (10 years vs 15 years in California). A precise explanation for this increase cannot be interpolated from the dataset. Multiple external factors may have contributed to this dramatic and steady increase, such as greater public attention to CT, "coding" and the promotion of CS K–12; an ongoing commitment by the University of Alberta's Department of Computing Science to nurturing a community of CS teachers through hosting regular meetings over two decades; the Faculty of Science's approval of five advanced CSE module credits for admission, and quickly expanded to universities across the province; the Faculty of Education's addition of a Bachelor of Education with a major and minor in Computing Science, and thus expanding the number of CS teachers in the province; and/or some combination of these and other variables.

Because data were only available at the school authority level, it is difficult to differentiate program growth within schools from program introduction to new schools in a district. Are more students taking CSE at each individual school? Or are new CSE programs popping up in more schools and then growing to reach their capacities? Bruno and Lewis (2022) and the Royal Society (2017) cited 79% of Californian and 70% of British high school students had access to CSE courses. However, we do not know what this number looks like in Alberta or Canada as a whole. Whether there are more CSE students per program or more CSE programs overall (both are indicators of an increased desire for CSE), policymakers may make alternative decisions with better information on whether existing programs are growing or stagnant. Further research could address this deficiency but would require access to data at the school instead of the district level.

Access to school-level data may also provide a deeper level of understanding with respect to rural-urban differences. Rural CSE has not grown at nearly the rate it has in urban areas (10.9% average annual growth vs. 34.4% in the cities). These disappointing rural CSE growth rates are consistent with the Royal Society (2017) who reported 31.1% of urban city schools currently offer CSE compared to only 11.2% in rural hamlet areas. The Royal Society suggested urban areas with universities and employers may have increased support. Though the suburban group provided an interesting subset group, growth has behaved much the same as in the cities they neighbour (36.9% average annual growth vs. 34.4% in urban areas). The small urban subset group (cities that are not near to the major urban areas in Alberta) saw nearly double the average growth rate at 67% per annum. Some of this disambiguation may again be a function of access to qualified teachers who can incubate new CSE programs in high schools. Warner et al. (2019) cited the WeTeach_CS program as a possible positive driver of inservice CS teacher education in the United States, increasing the number of certified CS teachers in rural areas by 178% compared to 63% in urban areas. Locally, the University of Alberta Faculty of Education began graduating teachers with computing science teaching majors and minor in 2011. Thus it may take time for CS subject area expert teachers to dilute throughout the province (Hoover, 2011).

Advanced CSE modules are growing at a much faster pace than introductory modules. This implies more students are being retained in CSE programs beyond introductory first-year CSE option classes. For example, 3000 level advanced classes showed the strongest annual growth at 66.6% in contrast to the 27.1% in 1000 levels classes. As 3000 modules typically represent grade 12 level advanced learning, this points to a healthy CSE system that is graduating HS students with three years of CS coursework. One of the factors driving the rapid increase in enrolments in advanced level CSE modules may be the University of Alberta Faculty of Science's 2011 addition of Computing Science ADV (CTS-5Cr) as one of the high school admission courses (Hoover, 2011; University of Alberta, n.d. -a). Post-secondary institutions across the province quickly followed the University of Alberta's lead. Additionally, students are able to use CSE modules for up to 20 credits towards their high school diploma, raising their attractiveness to some populations (Alberta Education, 2022a).

CSE module growth, however, did not have an equivalent effect in all geographic environments across the province. Urban and suburban data showed an increase in annual growth rates at more advanced module levels (see Table 3), as was the overall trend. Small urban centres, however, saw consistent growth across all module levels—perhaps indicating a more controlled program growth with less flexibility to add teachers to teach in certain module areas.

Gender did not have a significant effect on CSE growth rate (female growth = 312% vs male growth = 300%) over the duration of the investigation. Large growth rate indicates CSE as a whole is gaining popularity throughout the province, regardless of gender. That said, female module completion in high school remains a small percentage of CS course completions (13.5% of total). This falls roughly in line with CS enrollment data for undergraduate university programs (Ching et al., 2021; Hayes, 2010; Sax et al., 2017) in high school computer science in other jurisdictions (Bruno & Lewis, 2021, 2022; Floyd, 2021; Hazzan et al., 2019) and in the computer science workforce (Dionne-Simard et al., 2016). Although initiatives to encourage specific female interest in CS, such as WISEST (Goings et al., 2021) or Explore STEM (Franklin, 2018; Hoover, 2011) may be a positive influence on STEM as a whole, their effects have not yet been reflected in high school CSE enrollment patterns. If uptake rates for females remain in lockstep with those for males, promotional tools targeted at females may need to start earlier to close the gender gap. Recent research suggests that interest in CSE begins in early elementary school and female-aimed initiatives to encourage ongoing participation may also be necessary in early education (Guo & Ottenbreit-Leftwich, 2020; Kjällander et al., 2021).

On closer inspection, however, the female growth effect is more pronounced as course levels advance, especially with respect to estimated CSE retention from year to year. Retention of female students does appear to be increasing at a faster rate than for males. Although 100% retention (all students returning for the next grade level version of a course) is improbable for any option subject, females in CSE have shown an increased rate of retention over time. From grade 10 to 11, male student retention was stagnant over the study duration (42% average retention, -0.02% growth per year) while female student retention increased (28% average retention, 0.92% growth per year). Retention overall is lower on the female side, but it is increasing. A similar effect can be seen from grade 11 to grade 12—male retention increased (68% average retention, 2.21% growth per year) but female retention increased more rapidly (62% average retention, 3.83% growth per year). Although these small annual increases in retention may seem insignificant, if these trends continued along similar lines for the next decade, female retention in CSE would equal and perhaps surpass that of males. Encouraging retention in CSE is one factor that could help to reduce the extant gender gap (Gisler et al., 2018).

Further research investigating why retention rates are increasing is required to better understand how we might expedite this process for females. Cheryan et al. (2015) suggested, for example, that broadening representation in CSE, specifically with respect to CS educators and industry leaders, may help to bridge the gender gap in interest and sense of belonging. Overall, however, the issue of gender equity in CSE is complex and requires further research to identify the factors contributing to gender inequity in Alberta. Qualitative follow up with students who had completed some or all of a CSE program in Alberta would be critical to better understand the reasons for these trends.

Stephenson and Dovi (2013), speaking on behalf of the influential CSTA, stated that addressing gender equity imbalance is one of the foundational elements in the work of CS educators. They suggest a systematic approach is needed to improve K–12 CSE and reconcile the existing inequities surrounding gender. Our research is an initial part of the systematic approach to investigate the degree to which such gender inequities exist in Alberta's high school CSE context. Though our research will not offer solutions to this complex problem, understanding that gender barriers do exist in Alberta CSE is critical to situating our study and aligning the Albertan context to what is happening in the rest of the world.

Urbanicity has a more pronounced effect than gender on CSE growth, especially for females. Total rural growth rate in CSE has lagged behind urban areas but the effect is especially pronounced in rural female students with a 0.7% annual growth rate (compared to 15.4% in rural males). Consistent and substantial female growth in all other urbanicity cohort groups (urban, suburban, and small urban) makes this stagnation especially concerning. Potential explanations have been hypothesized in research and could include a lack of exposure to CS (Vilner & Zur, 2006), existing stereotypes of CS courses (Graham & Latulipe, 2003; Pau et al., 2011; Vilner & Zur, 2006), or existing gender gaps in similar and common co-requisites subjects like mathematics (Wilson, 2002).

Overall, Alberta's CSE is increasing rapidly in popularity. Although nearly all subset groups in Alberta CSE programs are growing, rates of growth are not equal. There are a few notable trends: urban areas tend to grow faster than rural areas, retention of students in more advanced levels of CSE is increasing, and growth in male and female subset groups are similar. Though specifics are not fully understood, we can point to some potential drivers of CSE growth—implementation of an updated curriculum more in line with postsecondary CS (2009), adding CSE as a university admission subject in Alberta (2009), and graduating new expert teachers with CS teaching majors (Hoover, 2011). Further understanding of these data requires more in-depth analysis with additional variables and subgroups separated out.

Future Research

Numerous areas are worthy of further investigation. First, an examination of module completion patterns across subject areas would be a valuable follow up to this article. Understanding modules that are taken (and not taken) in parallel with CSE could be critical information for teachers, school administration, and post-secondary admissions offices. Are students taking CSE instead of other sciences such as biology or chemistry? Are students commonly taking CSE alongside high-level math modules or completing CSE without math support? Are there traditional option courses that are losing registrants to CSE? Answering some or all of these questions may allow teachers and administrators to better understand the emerging needs of their student populations and plan for the future based on these enrollment patterns.

Second, analysis between schools within the same school districts could provide further insight into why we observed differences in growth trends with respect to module levels, school authority, urbanicity, and gender. Large school districts (Edmonton and Calgary public schools in particular) would require a more detailed analysis with completion data at the individual school level. Some smaller urban districts saw single-digit module completions for the first half of this period and then rapid growth more recently. Anomalies like these would require a closer examination at local sites where changes may result from the district or school-based priority changes, or the initiatives of an individual teacher. Evidence of this nature could serve as a valuable tool in identifying and modelling effective practices for implementing new CSE programs in a school or school district.

Third, an investigation of whether high school students are increasingly using CSE module grades as part of their post-secondary entry admission GPA requirement. For example, the University of Alberta requires two sciences (biology, chemistry, physics, or math 31) for admission to the Faculty of Science (University of Alberta, n.d. -a). Are students substituting one of the subjects with CSE (as a direct result of the admission requirement changes)? Are high school students taking CSE because they want to take more CS in post-secondary education? Are they using it for admission to alternate postsecondary faculties outside of Alberta? This research would require linking students' high school and university entrance data and program choice. Evidence of this could highlight which university level programs students are using CSE modules to gain admission to and provide feedback on the effectiveness of high school CSE recruitment.

Finally, the impact of COVID-19 on Alberta CSE HS enrollment could be investigated with a simple repeat of this analysis over the last two years of data. As Crick et al. (2020) noted in their recent paper on pandemic CSE, online shifts required during COVID-19 may permanently affect the way computer science is offered. It may also be critical that CSE is not an official core academic subject in Alberta and that likely affected the way it was treated during COVID-19 school shutdowns and subsequent online delivery models. This was partially investigated in the McCashin et al. (2022) paper on CSE during the COVID-19 pandemic but would require a more in-depth data set for full investigation and a better understanding of the reasons for continued growth through the COVID-19 pandemic timeframe.

Conclusions

In 2010, CSE was established as a distinct occupational area in Alberta's CTS curriculum with CS course offerings significantly expanded at the introductory, intermediate, and advanced levels. Since that time, student completion rates of high school computer science modules in Alberta have steadily increased, averaging 33.5% annually. Increased module completion indicates an overall growth in CSE course completion. Growth rates were similar among males and females, however females continued to take CSE modules in proportionally lower numbers (86% of CSE completions were male in both 2009/10 and in 2018/19). All geographic areas in the province experienced growth in CSE module completion, but the rate was slower in rural areas (10.9% annual growth) and faster in urban areas (34.4% annual growth), including those furthest away from Alberta's two biggest metropolitan areas (small urban = 67.0% annual growth). Notably, advanced level CSE module completion rates have also increased (66.6%) and retention of students from grade 10 to 11 and grade 11 to 12 is increasing. Further investigation is required into CSE module trends and patterns in Alberta: to explore potential causation of CSE growth, to understand emerging CSE program success stories, to understand continuing disparities (among female and rural students), and to inform future CSE curriculum development and practice in the province.

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Note

1. Prior to 1997 and the creation of the CTS program of studies, components of CS, such as programming, were part of the old Electronics Industrial Arts Education Program of Studies

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