Visualization of the Digital Divide Among K-12 Students: Open Data, Quantitative Measures, and Policy Implications

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Abstract

Our work utilized a multi-disciplinary approach to assess the digital divide among K-12 students through socio-technical and economic analysis. Results show that access to high-speed internet (broadband) and use continued to be a challenge for children and schools located in disadvantaged communities. Three visualizations were developed to display the digital disparity at the county level across our country and to support decision-making in resource allocation to improve broadband access and utilization.

Purpose

The year 2020 is an unforgettable time for many people and the impact of the COVID-19 pandemic is still being evaluated. Due to social distancing and other strategies to slow the spread of the coronavirus, school-aged children are impacted the most due to interruption of schooling (Garcia & Weiss, 2020; Kuhfeld et al., 2020). Students without broadband access and suitable digital devices at home became excluded from the learning opportunity that was once accessible in a school setting. For many students in the United States, the lack of reliable internet and technologies (such as a keyboard-enabled device, or personal computer with peripherals) outside of their classroom were existing challenges before the pandemic. The "homework gap" is one of the well-known issues that has been documented and studied in recent years (Calabrese & Nasr, 2020; Horrigan, 2015; Reisdorf et al., 2019).

This work was initiated by an educational data challenge, where broadband data was released, to investigate the educational digital divide in the United States (Open Data Institute, 2020). We integrated the fixed terrestrial broadband (i.e., cable, fiber, copper, DSL) data with public school administrative/financial data, and Census information to further elucidate digital inequality among K-12 students who attend public schools in the U.S.

Theoretical Framework

Before COVID-19, there were existing barriers for students to access learning outside of their school. The digital divide is often discussed from the perspective of access (Servon, 2002;

Grubesic & Murray, 2002; Riddlesden & Singleton, 2014), affordability (Chao & Park, 2020; Cotten et al., 2011; Gonzales, 2016), or use (DiMaggio & Hargittai, 2001; Warschauer, 2003) among the general population within a country or across countries.

The earliest discussion of the digital divide among school-aged children by Attewell (2001) observed differences in internet access and computer use among children between affluent and poor neighborhood schools in America. The digital divide has been traditionally viewed as a binary divide between those who have and have-nots to telecommunication tools and personal computers. The changing nature of technology (i.e., internet technology and services, digital devices, and software application) and its integration into daily routines for adults and children require flexible solutions that can evolve over time and space.

Several scholars (Dolnicar et al., 2004; Hilbert, 2014; Ragnedda, 2019) describe the current digital divide in a three-level conceptual model where the first level is physical access, the second level is usage and skills, and the third level as tangible benefits in social and economic terms where inequalities exist. We applied this conceptualization of the digital divide and operationalized the factors quantitatively for meaningful comparison across the United States at the county level.

Methodology

Our team adopted a multi-disciplinary approach where educational measurement and economic principles are used to operationalize the three levels of the digital divide. A composite measure of digital opportunity (SDO) was created (Jim, 2021) to allow cross-country evaluation of all necessary components students should have before participating in digital/remote learning. A factor analysis with principal axis factoring is used to assess the latent dimensions between the selected variables based on their correlation with standardized scores derived with the Anderson-Rubin methods (DiStefano et al., 2009; OECD, 2008). The SDO score is designed to be used at the county geographic level across the U.S. The SDO measure represents four components: access, usage, speed, and ownership of PC with internet subscription. A benefit-cost analysis was conducted to generate a benefit-cost ratio to show the relationship between tangible social and economic outcomes with the investment cost of improving digital access and internet quality. The two measures are presented in a map form through data visualization to show the disparity of various factors of the digital divide among counties that have public schools in operation.

To develop a final dataset for this educational data challenge, we first identify related factors associated with the digital divide among students in public education. The following open datasets are aggregated at the county level: public school administrative and financial data (NCES, n.d.; 2019), ACS 5-yrs estimates on computer/internet at home for households with children under the age of 18 (U.S. Census Bureau, 2019), rurality measure (U.S. Census Bureau, 2010), SES measures from the Stanford Education Archive Version 4.0. (Reardon et al., 2021), broadband usage dataset (Misra et al., 2020), and speed information from Broadband Now (2021) data. While the terrestrial broadband data have information at the zip-code, county, and state level, we chose to focus on the county level for this preliminary phase of the study to provide an overview of the nation’s status.

Data Processing and Imputation

The school level information served as the base layer and the other datasets were appended to it at the county level by the unique county ID made available from the Census data. This method allows us to use the schools as the location markers where K- 12 students receive their formal education. The associated datasets appended to the school by regions aided the investigation of digital infrastructure, broadband access and usage surrounding the schools.

The broadband usage dataset (Misra et al., 2020) have a few missing values for counties when joined to the school data in the state of Alaska, South Dakota, and Virginia. The Broadband Now (2021) data had missing values at the zip-code level that have no reported population or low population (<1000) per ZIP. After the data merge, missing values were imputed at the county level. A random forest method was used (missRanger by Mayer, 2021) for mixed data types. An evaluation of the imputed values was conducted such as checking values of counties with comparable population in the same state with the assumption that access and usage rate would be similar within a state.

Research Questions

1. How does broadband access and use vary for K-12 public school students at the county level across the United States?

2. What are the cost barriers (by geography) that are needed to obtain the projected digital education benefits?

Results and Discussion

The list of variables and their data sources used to construct the two described measures (SDO and Benefit-Cost Ratio) along with broadband information for the interactive maps are listed in Table 1. Other factors such as Title I status, locale classification of schools, and county rurality were also used to inform our analysis. It is important to note that we observed a non-linear relationship between the degree of terrestrial broadband access to internet usage (broadband speed at 25 Mbps) at the county level during data exploration (Figure 1).

Descriptive Statistics

A descriptive analysis and correlation with *Pearson r* were conducted on broadband access, usage, home with PC and internet subscription, and rurality at the county level. A moderate positive relationship is observed among broadband access and use ($r = .67$). However, the relationship between broadband access to ownership of PC and internet at home ($r = .27$) with school-aged children is weak, indicating that access to broadband does not assure PC ownership or internet use at home. Based on this observation we suspect that adoption could be the concern if we are to address the digital divide. For example, even if families subscribed to broadband internet at home, do students have access to a computer (PC or laptop) that allows the same interactive experience (such as typing with a keyboard, suitable screen size for reading, or compute mathematical formula) at home. We also observed moderately inverse relationship between rurality to access (*r* = -.54), usage (*r* = -.68), and internet speed (*r* = - .46). This indicates that schools and students located in rural area continue to have less access and less utilization of high-speed internet.

Table 1. Selected Variables and Data Sources

Measure	Variable	Data Sources
Students Digital Opportunity	Percentage of Broadband Availability	Broadband Now (2021)
	Percentage of Broadband Usage	Microsoft (Misra et al., 2020)
	Median Speed (Mbps) at the County level	Broadband Now (2021)
	Percentage of Home with PC and Internet Subscription (with school-aged children)	U.S. Census Bureau ACS (2019)
Benefit-Cost Ratio	Percentage of Broadband Availability	Broadband Now (2021)
	Estimated Number of Households	U.S Census Bureau ACS (2019)
	Lowest Monthly Internet Plan Price (Reported by Internet Service Providers)	Broadband Now (2021)
	Percentage of Home with PC and Internet Subscription (with school-aged children)	U.S. Census Bureau ACS (2019)
	Estimated Median Household Income	U.S Census Bureau ACS (2019)
	Total Number of Student Enrollment	NCES (n.d., 2019)
	Number of Full-time Teacher	NCES (n.d., 2019)
	Average Annual Salary of Teachers	NCES (n.d., 2019)
Maps	SES Measures of Students at the County Level	SEDA 4.0 (Reardon et al., 2021),
	Total Number of Student Enrollment	NCES (n.d., 2019)
	Percentage of Broadband Availability	Broadband Now (2021)
	Percentage of Broadband Usage at 25 Mbps	Microsoft (Misra et al., 2020)
	Lowest Monthly Internet Plan Price (Reported by Internet Service Providers)	Broadband Now (2021)

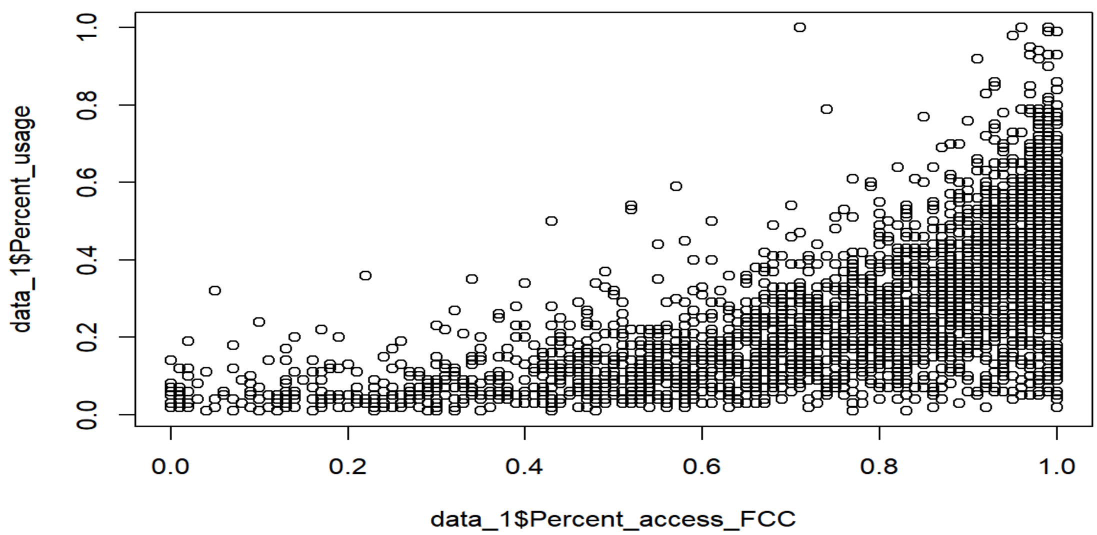

Figure 1. Scatterplot of Percentage Access vs. Percentage Usage of Broadband per County (n = 3138)

Visualization and Interpretation

Three interactive maps (Jim, 2021) were built to visualize the digital divide among K-12 students, cost-benefit ratio, and broadband availability and pricing at the county level. The broadband pricing and availability map allows viewers to examine the reported broadband access, usage, and pricing information during 2019 (Figure 3).

There are 3138 counties in the final dataset with a total of 94,619 operating public schools. Three counties were excluded due to no presence of K-12 public schools in that region during the 2017 - 2018 school year. A total of 50,266,116 K-12 students were reported in enrollment at these public schools. The Full-Time Equivalent (FTE) for teachers estimated a total of 3,052,597 at these K-12 public schools (NCES, n.d.).

The Students Digital Opportunity (SDO) is a standardized score with a mean of zero. It represents the public-school students' relative position of connectivity within each county (Figure 2). By using the SDO score for comparison, approximately 11.5% of all public-school students in the U.S. are below-average in their digital opportunity. These students are enrolled within 17,555 public schools across 1781 counties in the U.S. (Table 2). Although the percentage of schools in areas with a below-average digital opportunity is only 18.6% of all K-12 schools, they represented 56.8% of counties within our country (Table 2).

The benefit-cost ratio (BC Ratio) was established to inform resource allocation decisions between public and private investments (Figure 4). For benefit-cost ratio, a value below 1 means any amount invested will not have a 1-to-1 return on the initial cost. According to our analysis, there are 1844 counties (58.7%) with a benefit-cost ratio below 1, which is where 14,890 K-12 schools are located, with about 4,342,711 K-12 students enrolled at these schools (see Table 2).

Last we combined both SDO and BC Ratio to determine the number of counties that have both conditions: a less than 1 BC Ratio and below average (< 0) SDO score. Table 3 provides the count and percentages of how many counties met both conditions as well as the number of schools, students, and full-time teachers who were reported at those regions. Nearly half of all counties in the U.S. (47.4%) have both conditions, meaning their students' digital opportunity is below average, and return of broadband investment is not profitable (below 1 on BC ratio). While it is not economically attractive to private companies to expand their digital services and infrastructure into the rural and remote areas, the options on broadband choices and upgrades are also limited in these regions.

By percentages, a smaller portion of K-12 students and teachers (12.2% of schools) nationally are affected by the lack of digital infrastructure in their regions, to fully reconcile the digital divide we must develop more appropriate technologies and effective policies that will better serve students and their families in the rural and remote parts of the country.

Table 2. Descriptive Summary of K-12 Students and School by County per Measure

Measure	Count (Percentage)	Count(Percentage)
Students Digital Opportunity	**Relatively below average (< 0)**	**Relatively above average (> 0)**
Number of County	1781 (56.8%)	1357 (43.2%)
Total Student Enrolled	5,777,902 (11.5%)	44,488,214 (88.5%)
Number of K-12 Schools	17,555 (18.6%)	77,064 (81.4%)
Benefit-Cost Ratio	**Return of Investment below 1**	**Return of Investment above 1**
Number of County	1844 (58.7%)	1297 (41.3%)
Number of K-12 Schools	14,890 (15.7%)	79,729 (84.3%)
Total Student Enrolled	4,342,711(8.6%)	45,923,405 (91.4%)

Note. There are no schools or students placed exactly at zero for SDO measure. There is no county placed exactly at 1 for benefit-cost ratio.

Table 3. Combined Count of K-12 Schools, Students, and FTE Teachers by County

SDO below 0 and BC Ratio below 1	Count (Percentage)
Number of Counties	1488 (47.4 %)
Number of K-12 Schools	11,550 (12.2 %)
Total Student Enrolled	3,343,926 (6.7 %)
Full-Time Equivalent Teachers	232,936.2 (7.6 %)

Note. County is used because it is a primary legal division of most states. see U.S. Census Bureau (2016) Terms and Definitions for more information.

The three visualizations were built to inform decision-making in regard to disparity in digital opportunity among K-12 students, affordability of broadband subscription, as well as the return of investment to digital infrastructure development. As we observed by interacting with the maps, SES values and student digital opportunity (SDO) do not always move in the same direction, which is evident in the complexity of the digital divide in our country. This aspect warrants further research as to how structural factors vary across states and how it influences the availability of broadband and technology for school-aged children at the local level. If the current educational goal continues to require regular use of the internet and digital technology, especially learning at home with educational technology beyond school hours, access is still a persistent barrier for our students' population in K-12 education.

While K-12 public schools receive federal funding (FCC E-Rate Universal Service Program) to obtain affordable telecommunications and internet access at their facilities (Office of Educational Technology, n.d.), it is unclear on the difference between initial cost and maintenance cost for schools to provide access to the internet and technology within school and outside of school settings. Many states were able to address the digital divide during the pandemic by providing laptops and at-home internet connections for students (van Ness & Varn, 2021), however, the digital divide experienced by teachers and other staff who provides instructions and related instructional supports are unknown.

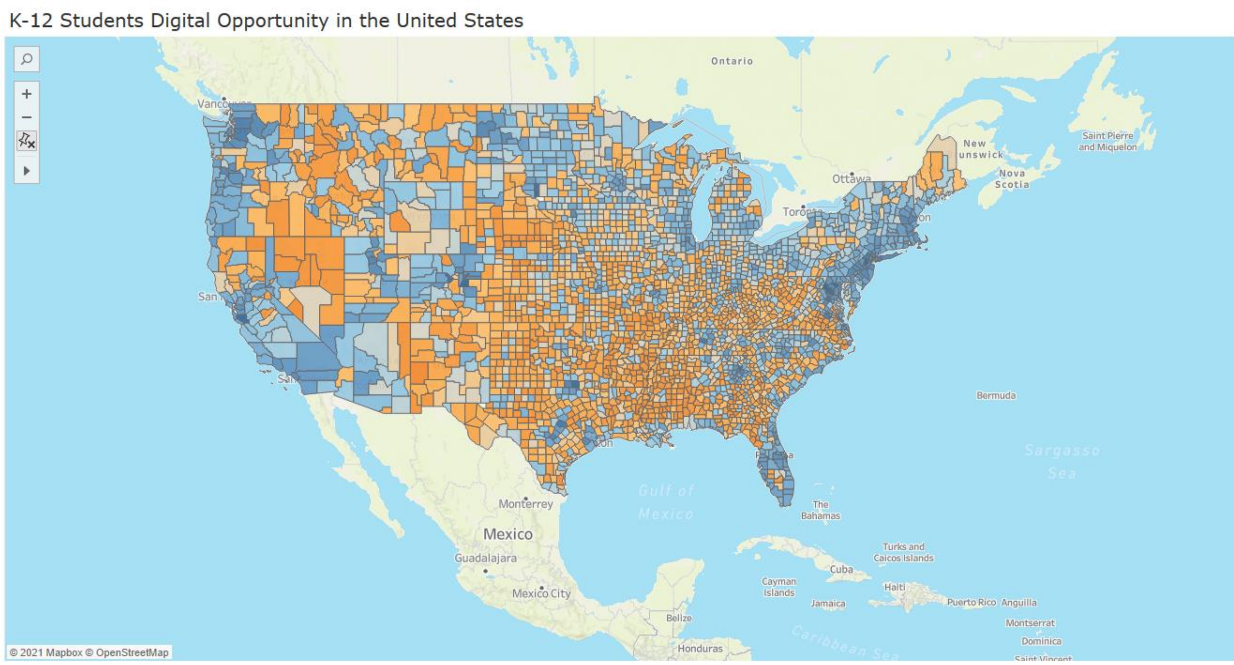

Figure 2. K-12 Students Digital Opportunity in the United States.

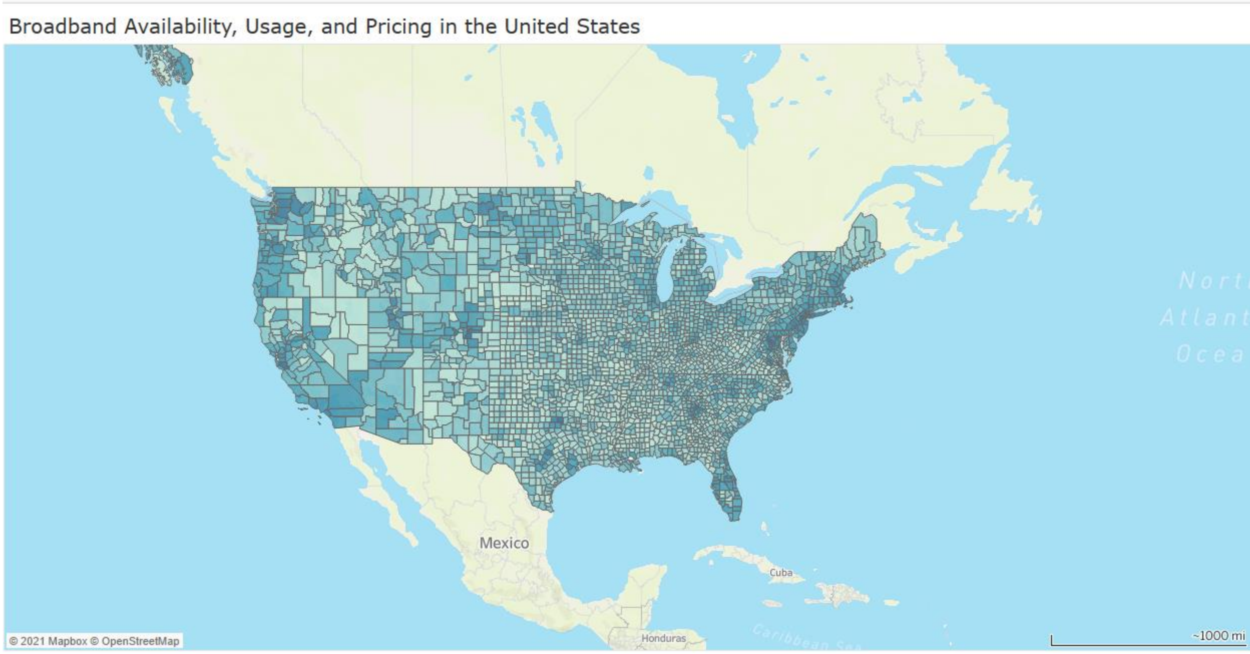

Figure 3. Terrestrial Broadband Availability, Usage, and Price information in the United States

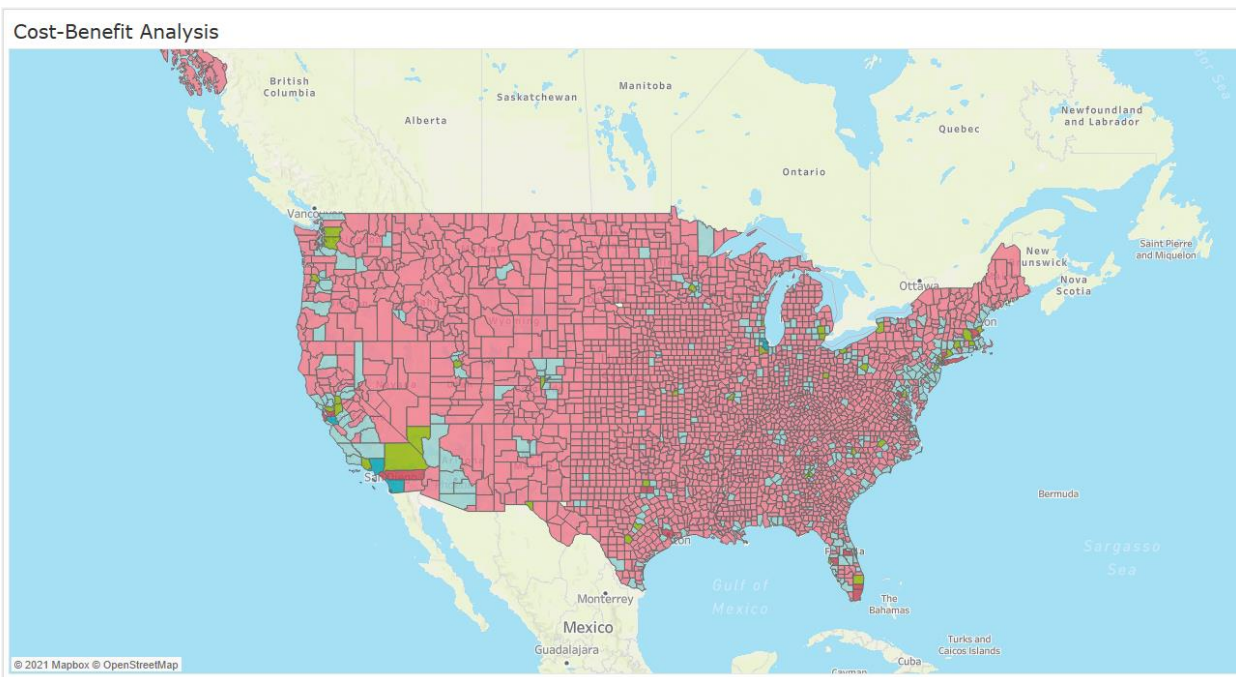

Figure 4. Cost-Benefit Analysis across County in the United States

Conclusions

The current public policy has been mostly focusing on internet access as a priority in our country. Our investigation revealed the discrepancy between broadband usage and access and thus adoption appeared to be a factor that is not apparent in the current discussion of the digital divide. For K-12 students, access to the internet and digital technology should not be optional.

This matter is more complex when it is compared to access and use among the adult population because children rely on others to provide basic resources. Previous studies have shown how non-users or non-adopters in the adult population (Brandtzæg et al., 2011; Warf, 2013) remain a challenge in our current society in order to close the digital divide. There are also ethnographic studies at the school level to understand how students navigate the technological challenges in their classrooms and schools (Rafalow, 2020; Watkins et al., 2018). These studies have pointed to school-level policy, instructional practice, and curriculum as factors that may have widened the digital divide gap among certain groups of students. Based on our current analysis, access to broadband internet and keyboard-enabled digital devices among K-12 students should be part of a “basic school supply” in our current education system if the goal is to equalize the student’s digital opportunity.

The open data allowed us to examine the disparity of internet access and usage of broadband internet and related technology where schools are located. Campos-Castillo (2015) argued that determining the first level of digital divide should be continued because there are still a lot of ambiguity of “who has internet access” and if the divides are changing across time in the U.S. Therefore, the availability of public data in the upcoming years will be important to see if there is a shift in broadband access and use across our country and how does technology access and use look like within schools. More elaborated information on the types of broadband internet will also be informative due to the technical differences between cable, fiber optics, copper, and DSL connection at the ground level.

There are nuances at the community level where different aspects of locale difference could contribute to the discrepancy, we observed at the larger county scale. Further examination of broadband access and use at a more refined geographical layer (e.g., neighborhoods within a state or bioregion, such as remote mountains, heavily forested area, coastal islands) is needed to pinpoint what other factors (e.g., social demographic or cultural aspect) may contribute to broadband adoption at the school or district level. Such an approach will deepen our analysis further to better inform educational policy and resource allocation.

Educational Implications and Policy Recommendations

For a complex issue like the digital divide, our study demonstrates the integration of data science, educational measurement, and economic analysis to address the current research gaps of the digital divide among K-12 students in the United States. Our research product in a form of interactive maps provide policy makers a more robust understanding of the digital divide and its complexity. Our preliminary findings point to several educational and policy recommendations.

Our cost-benefit analysis shows that many counties’ benefit-cost ratios are below one which indicated that initial investments in infrastructure may be too high for these areas to provide greater access and quality of broadband internet. This result points to the need for state and federal investments to address the digital infrastructure issues in low benefit-cost counties. However, even with the release of federal funding to expand broadband infrastructure, it may take years for it to be operational before students can benefit from this technology. Historically, broadband deployment or upgrades tends to occur in areas with higher economic activities (Ford, 2018). Therefore, most of the rural areas continue to fall behind in digital infrastructure and broadband development. To ensure access and reliable broadband services for K-12 education, it requires a collaborative approach between the federal, state, and local levels. Due to the variation of state-level broadband policy, efforts should be directed to remove policy barriers for local broadband expansion and prioritize fiber-optic for schools. It is worthwhile to investigate E-rates and school funding mechanisms in terms of broadband and digital technology for students to use in school and outside of school.

From an equity perspective, we propose considerations to allow equal learning opportunities. For education technologists, content creators, and software developers, offer options in e-learning that can accommodate low speed or bandwidth situations can benefit many students. While there is still a disparity of access to high-speed internet and digital device, these considerations will ensure students are receiving the content promptly to provide a quality learning experience.

Even though we were not able to determine the digital divide experienced by teachers at the K-12 schools, improving physical access in high-need areas with targeted training and resources for parents and teachers could benefit students as well. Supporting teachers and the students' families of their educational needs with digital technology are especially important. The changing nature of technologies will be a continuous challenge. School administrators and district leaders will need to stay informed and think of technology as an integrated part of their facilities and services to the students and their families.

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Tableau interactive maps can be viewed online:
https://public.tableau.com/views/EducationOpenDataChallenge-D2IETeam/SDO?:language=en-US&:display_count=n&:origin=viz_share_link

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