OVERCOMING LOW BANDWIDTH IN AN INCREASINGLY ONLINE EDUCATIONAL WORLD

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By

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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One of the primary challenges that comes with developing applications for the Internet is the ability to deliver large amounts of content and data in a reasonable amount of time. As the Internet has matured, so too have the websites and web applications that live on it. More advanced websites require more and more data to be transferred over an Internet user's network. However, the rate at which Internet service providers (ISPs) in America upgrade and expand their infrastructure is markedly slower than the rate at which websites and society's reliance on them have evolved. While many Americans take near-instantaneous load times for granted, many others experience noticeable delays while they attempt to interact with the Internet, a result that is directly correlated to the bandwidth of the user's regional network and the efficiency of their home's Wi-Fi (Busby et al., 2021).

The technical report attempts to provide practical solutions for web developers seeking to address this issue. It describes a personal experience in developing a web application for a local business, and the process of optimizing it for the modern Internet. The three main components of a web app, the front-end user interface, the back-end logic, and the database, are explored in-depth, with recommendations given for common use cases. The report, written under the guidance of Professor Daniel Graham, Department of Computer Science, serves as an outline for others to follow when attempting to develop applications of their own.

The STS research paper examines the issue of low-throughput networks from the converse perspective of the end users. Specifically, the goal of this research project is to investigate how American students are affected by low-bandwidth networks. It explores the regional and economic disparity in broadband access throughout America, and then applies Actor-Network Theory (ANT) to the current state of online education during the COVID pandemic (Law & Callon, 1988). This analysis provides a framework to understand the

ramifications of online-only classes and how they can unintentionally widen the divides between socioeconomic groups of students.

The tightly coupled topics address the issue of unreliable networks. The technical report explores potential solutions to this problem, and the STS topic analyzes the effects of this problem on American students and society. Together, they provide a holistic examination of the current Internet access paradigm in the United States. Understanding a problem in full is key to an engineer's job to provide an appropriate and coherent solution.

COVID PANDEMIC PUSHES AMERICAN CLASSROOMS ONLINE

The COVID pandemic completely transformed the way in which American students participate in their educational experience. Assignments which were once handed out and submitted in class via hard copies are now posted exclusively online, with students expected to submit them to their instructors through online file systems. Online classes are typically delivered in one of two ways: synchronously or asynchronously. Synchronous classes do not meet in a physical location, but rather inside of an online meeting room through video streaming applications like Zoom. Asynchronous classes do not meet at all. Instead, instructional content is delivered to students in a way that allows them to access the material on their own time. Typically, this comes in the form of online videos and worksheets (Francom et al., 2021, p. 592).

Some schools attempted to implement a combination of online and in-person instruction, called hybrid instruction, as a way of providing the benefits of face-to-face education while maintaining some of the safety of online learning. In early 2021, approximately 21% of American middle-school students were enrolled in hybrid instruction, with 50% of their schools offering hybrid learning as an option (National Center for Education Statistics, 2021). Kazu and

Yalçın find in their meta-analysis of previous research that the effect of hybrid learning on academic achievement in a certain class is dependent on that class's subject (2022). Hard sciences like biology are better aided by hybrid learning because of the use of in-person labs which are unavailable in an online setting. Math courses which mostly consist of formula memorization and pencil-paper worksheets, on the other hand, do not find a significant advantage in hybrid learning (Kazu & Yalçın, 2022).

The way in which students are expected to "go to school" has completely changed, bringing into question the ability to succeed of those who cannot afford, or simply do not have access to, the necessary technology. While this problem has been around for as long as schools have used the Internet to deliver course material, the COVID pandemic has served to magnify its effect (Cook & Grant-Davis, 2005). Due to the recency of the pandemic, its effects have yet to be fully realized. The goal of this research project is to investigate how different groups of students have been disparately affected by low bandwidth networks during online learning, and to identify potential solutions to the problem using ANT.

THE DIGITAL DIVIDE: NOT ALL STUDENTS HAVE EQUAL ACCESS TO THE INTERNET

The digital divide is a well-documented and long-researched phenomenon prevalent around the world, referring to the disparity in digital technology access between different groups of people. In regard to the Internet, it is the gap between those with access to high-speed broadband and those without (Grace et al., 2019, p. 2001). In 2021, the Federal Communications Commission (FCC) reported that at least 17 million American schoolchildren were without access to high-speed broadband. "High-speed" is qualified as having at least 25 Megabits per second (Mbps) of download speed and 3 Mbps of upload speed, commonly referred to as 25/3

broadband (Federal Communications Commission, 2021). To understand the effects of the digital divide, it is important to identify where this gap exists, and which groups are being divided.

One of the biggest indicators as to which side of the gap a student will fall is their location. Lai & Widmar find in their examination of county-level broadband data that a negative relationship exists between a county's rurality and its median Internet download speed (2020, p. 461). In other words, the further someone lives from a metropolitan center, the less likely they are to have access to high-speed broadband. One of the reasons for this phenomenon is that ISPs have a financial incentive to focus their development efforts on densely populated areas which provide the most customers for the least amount of infrastructure. The inhabitants of rural counties are more spread out, meaning that ISPs must provide more infrastructure to reach fewer amounts of people. Additionally, the servers and data centers that host and store web content are typically located near urban centers, resulting in increased latency, or download times, for those living further away (Liang et al., 2021).

Illustrating this point is the fact that in 2016, 39% of rural communities in the US lacked access to "true broadband", or 25/3 broadband (McCoy, 2020, p. 44). The caveat to this entire situation, however, is that even those regions *with* access to 25/3 broadband are not guaranteed to use it to its fullest extent. Figure 1 on page 5 shows that throughout the US, broadband availability does not correlate to broadband usage. Either due to pricing or infrastructure, Americans are not able to get the speeds that are expected of modern broadband networks (Kahan, 2019).

Undeniably, the digital divide is most apparent between economic groups. In upper-middle-income countries like America, 82% of children from wealthy households have home

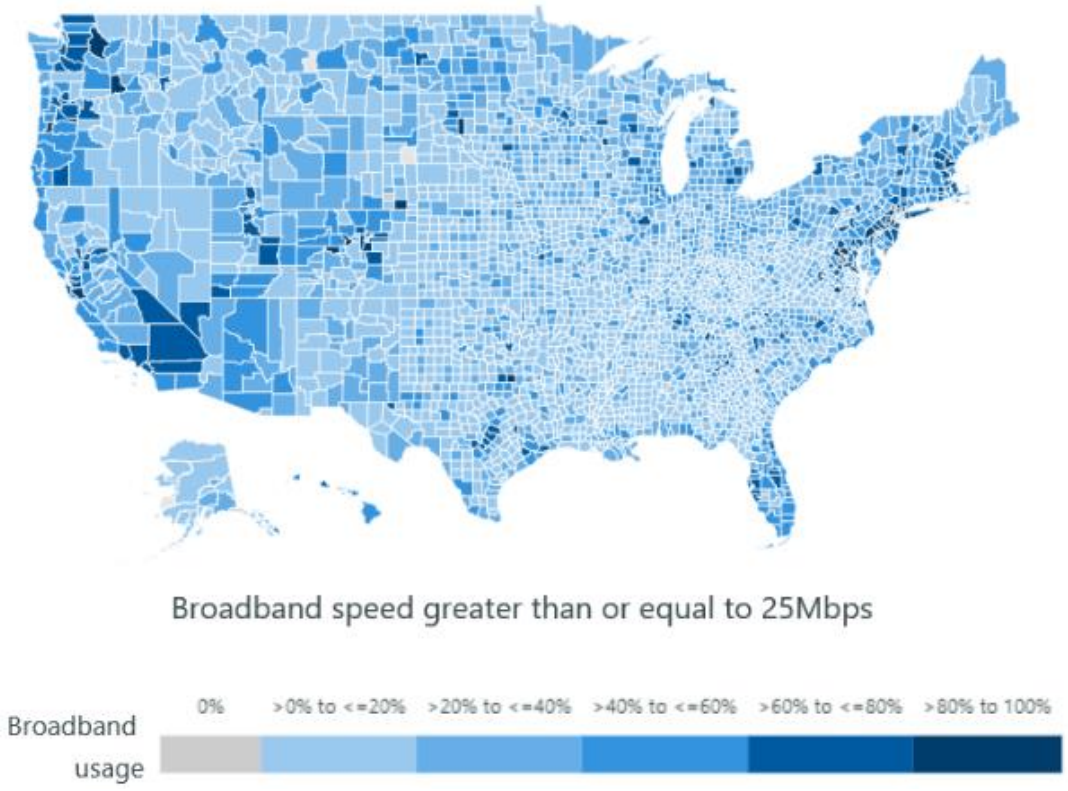

Figure 1: US Broadband Usage Heatmap. Displays areas that do and do not have access to "true broadband" (Kahan, 2019).

Internet access, compared to only 28% of children from poor households (UNICEF, 2020, p. 9). While not surprising, these statistics are staggering and indicative of a larger power inequality between higher- and lower-income American households.

Parents with the means to afford high-quality Internet access typically also have the means to purchase multiple household computers and top-of-the-line school supplies for their children. An analysis of US census data found a positive correlation between a household's income and its odds of having "high connectivity" – a term referring to households with a broadband Internet connection *and* a full suite of computing technology including at least one computer, one smartphone, and one tablet (Ryan, 2018, p. 2). Children in these households thus have more access to and avenues to interact with the Internet, making them more advantaged than their lower-income peers in an online setting.

RAMIFICATIONS OF THE DIGITAL DIVIDE ON STUDENTS

Most public schools and online courses lack the infrastructure to satisfy students of all Internet speeds. Those with slower speeds struggle to view and submit assignments while those who can afford to pay for faster speeds get the attention that they need from their teachers. Compounding this problem is the multimedia nature of many online learning materials, such as videos and streamed lectures (Rai, 2018, p. 273). These materials have very large file sizes, resulting in potentially long download times. For those that do not have access to a computer for an extended amount of time, they may have to initiate a download during one use session and wait until their next session to use the material. Attempting to access a live-streamed class poses its own problems. Streaming applications like Zoom will automatically reduce video and audio quality if a user's Internet connection is below a certain speed threshold to stay in-sync with the instructor. As a result, the video becomes blocky and nearly unwatchable, especially when the instructor attempts to share their screen (Shang et al., 2022, p. 1027).

A 2021 survey conducted by the Pew Research Center found that 46% of students in lower-income households faced at least one of three technology-related obstacles while attempting to learn in an online classroom: having to complete schoolwork on a cellphone, being unable to complete schoolwork due to lack of access to a home computer, and having to use public Wi-Fi because of an unstable home Internet connection. Only 18% of higher income households responded similarly (Schaeffer, 2021). These obstacles can be incredibly frustrating to children, especially younger ones who lack the knowledge to jump through the various technological hoops. Napoli & Obar refer to the students that interact with the Internet only through mobile devices as the "mobile Internet underclass" (2014, p. 323). Census data shows that these students are more likely to come from low-income households, indicating that they

cannot afford a dedicated computer, and resort to using a mobile phone or tablet for school purposes due to the cheaper price (Ryan, 2018, p. 2). Napoli & Obar liken the difference in Internet engagement between mobile and PC users to that of snorkeling and scuba diving. Mobile users can "skim the surface" while PC users can "dive deep" and become "totally immersed" (Napoli & Obar, 2014, p. 327).

It is worthwhile to note that there are socioeconomic factors at play that do not explicitly relate to the digital divide. For example, White teens in D.C. are "more than twice as likely to have received a vaccination than Black teens" (Stein, 2021, para. 17). Students attending predominantly Black schools which attempt to teach in-person may have to spend more time in quarantine than students at other schools, resulting in a stilted education experience that disproportionately affects Black teens and hampers their ability to get a standard education. While the roots of Black anxieties about medicine are outside the scope of this research paper, the conclusion can be drawn that the situation in D.C. is the result of a systemic imbalance of power.

THE DIGITAL DIVIDE BEGETS A SOCIAL DIVIDE

The analysis so far demonstrates that the gap between socioeconomic classes in America contributes to the digital divide. The digital divide, in turn, has had serious negative effects on rural and lower-income students' education in the switch to majority online learning. However, what happens if this analysis is taken a step further? What is the result of this growing educational divide?

The answer is that this paradigm is cyclical in nature. The growing inequality in educational experiences results in growing socioeconomic inequality. In an analysis of a Pew

survey on Internet users' demographics and types of Internet use, Buente seeks to determine if socioeconomic status and education affect the scale by which digital citizenship influences electoral engagement. He concludes that they do, stating that college-educated digital citizens are more likely to be politically engaged than their high school-educated counterparts (2015, p. 152). One of the potential causes that he presents is the difference in Internet activities that respondents took part in. Those who spent most of their time on the Internet watching videos, for instance, were shown to be less politically involved than those that read or shared the news.

Grace et al. discuss this topic in their study on how the structure of massively open online courses (MOOCs) can contribute to the digital divide (2019). In this paper, they make a distinction between "capital-enhancing" and "recreational" Internet use, similar to Buente's comparison of video-watching and social media to reading and sharing the news. They examine the effect of a MOOC's language on its accessibility to various socioeconomic groups and conclude that there are "properties of online content [that] make usage more accessible for some people than others" (Grace et al., 2019, p. 2012). In other words, the structure of many online educational tools advantage higher-income and higher-educated people while unintentionally setting up barriers for those who are less privileged. This serves to highlight why it is essential to address the digital divide. Its cyclical nature causes it to widen as time progresses and technology improves.

ADDRESSING THE DIGITAL DIVIDE

Attempting to provide an answer or solution to this dynamic requires a full understanding of the actors at play. The ANT diagram in Figure 2 on page 9 illustrates a distilled-down network, along with the relationships between various human and non-human actors. One of the drawbacks of ANT diagrams is that they represent all actors as having equal influence on the

network, a simplification which is typically not true in practice. Therefore, it is important to determine the most "powerful" actors, which in this case are regulators, specifically the FCC, due to their ability to enforce legal standards for Internet access.

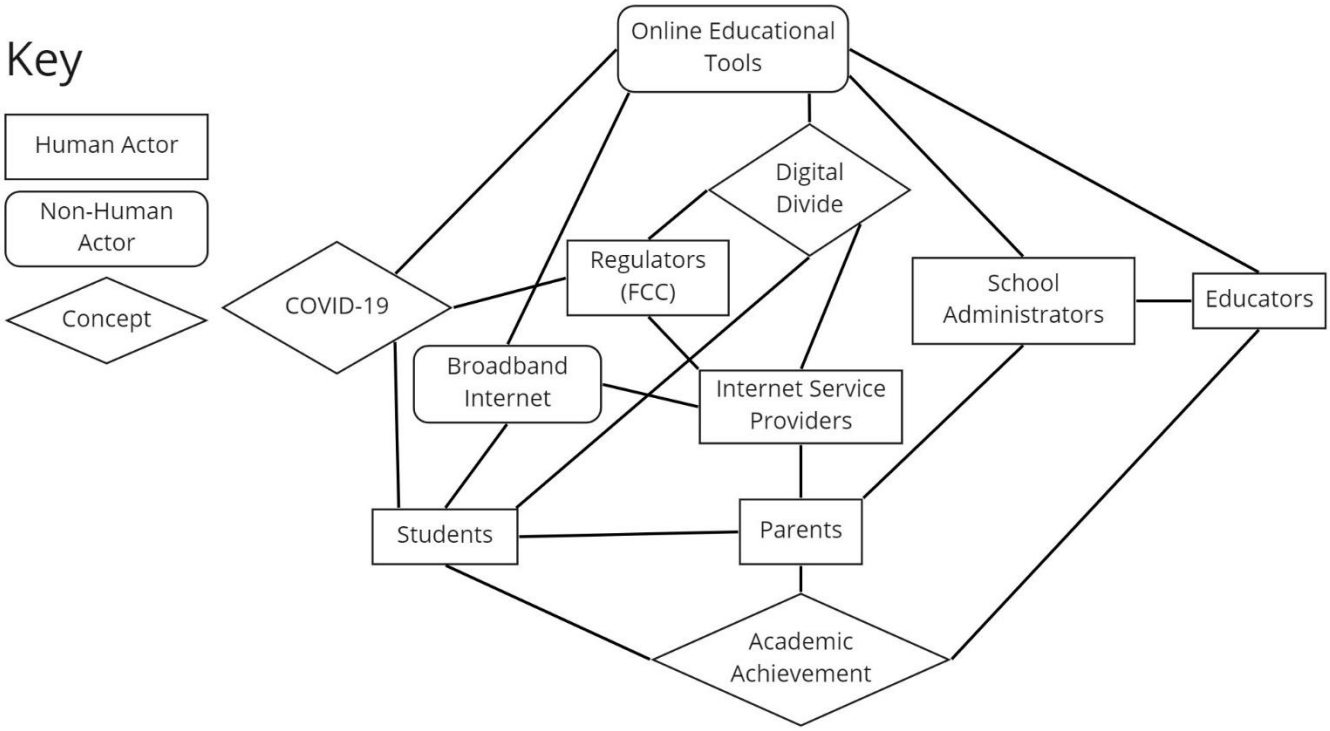

Figure 2: Online Educational Tool ANT Diagram. Visualizes the relationships between various human and non-human actors (Helmrath, 2022).

One of the most common recommendations for narrowing the Internet gap is to increase the definition of high-speed Internet. Jessica Rosenworcel, current chairwoman of the FCC, advocates for exactly this in a 2019 statement. She states that "broadband is more than a technology – it's a platform for opportunity," and recommends that the FCC modify its definition from 25 Mbps download speed to 100 Mbps download speed (Rosenworcel, 2019, para. 2). While this solution would benefit students, it only addresses Internet strength and not Internet access. Those students without access will not have their speeds, or lack thereof, improved by this measure.

However, in this same statement Rosenworcel alleges that the FCC is significantly underreporting the amount of Americans without Internet access, saying that "the claim…that there are only 21 million people in the United States without broadband is fundamentally flawed" (Rosenworcel, 2019, para. 6). In an independent study conducted by Busby et al., they concur and claim that ISPs are massively over-reporting their availability (2021, para. 6). Surprisingly, this also explains Kahan's findings in Figure 1 on page 5 that Internet access (as reported by the FCC) does not equate to Internet usage (2019). Because regulators are not working with the proper data, they cannot make accurate assessments on how to best remedy the issue of Internet access. Therefore, it is imperative that the FCC rebuilds its data collection tools and surveys from the ground-up so that ISPs are mandated to provide accurate information.

An alternative route to addressing the problem of student access to technology centers around school administrators and their ability to directly impact the lives of students and educators. Some school districts, to ensure that all students can access their classes during online learning, have begun to provide district-issued laptops to any students that request one (Macaulay, 2020). Students who previously would have had to use their family's communal desktop or a parent's mobile phone are able to engage properly with online content due to this measure. However, it is important to note that the funding of school districts is almost always directly related to the incomes of the households in the district. Most school districts with the funds to afford this type of mass-spending are typically those that contain a large amount of well-off and higher-income households when compared to lower-income districts. Additionally, this neglects to address the issue of Internet access, as a laptop without an Internet connection cannot be used for any online activities.

The analysis in this paper seeks to answer the question of how American students are affected by the digital divide, and leverages the research to review potential courses of action to even the playing field. The onset of the COVID pandemic forced students and educators to operate in a manner they had not expected. Systemic barriers to entry prevented many students from being able to experience the education that was intended for them. Two years later, many of these barriers are still present, with regulators failing to provide meaningful solutions. It is crucial that these barriers are addressed quickly, as their systemic nature means that it will take a long time to fully overcome them. While no one solution examined in this paper is perfect, they all serve to slightly bridge the digital divide.

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