

Enhancing Education in Underserved Schools: The Internet Backpack as Cyber-physical Infrastructure

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Abstract— This paper assesses the results of a STEM education pilot project bringing cyber-physical infrastructure for broadband connectivity, trusted devices, and secure cloud and privacy and rights-protecting edge cognitive computing and wireless services, to underserved New York City school children at Timothy Dwight PS 33X in the South Bronx, PS 91 Albany Avenue School and PS 316 Elijah Stroud Elementary School, both in Brooklyn, New York, USA. This pilot study, initiated in 2017, demonstrated how the innovative Internet Backpack could bring immediate connectivity and digital and physical (cyber-physical) resource-sharing including cognitive wireless networks to many school children simultaneously, much faster than previously thought possible, or affordable. Projecting from this successful pilot, in this paper we explain how we anticipate that the results will serve to focus further action by all stakeholders on the broadband underserved wherever they may be. We suggest utilizing the Internet Backpack to develop a gap-filling last few hundred feet road map of where broadband connectivity is otherwise lacking and hence hindering school children's education performance and opportunities to explore STEM learning topics. This model can guide future buildouts of broadband Internet and cyber-physical infrastructure to help address both the Covid-19 pandemic emergency and the ongoing, longstanding systemic societal emergencies exacerbated by limited Internet access in resource-constrained communities. Our initial pilot data shows improvement in both student scientific reasoning and science mastery when uninterrupted Internet connectivity is provided, allowing students to engage in both curricular and extracurricular science projects unimpeded by digital divides. Larger-scale studies, if replicating these results, could guide educators and policymakers towards utilizing cognitive systems such as the Internet Backpacks, and Science/IoT curricula, for efficient cloud to edge connectivity and innovative educational content, changing the equation for greater digital inclusion in urban and rural communities, quickly.

Keywords— *Internet Backpack, Broadband Connectivity, Digital Inclusion, Science Education, Cyber-physical Infrastructure*

I. INTRODUCTION

Access to the Internet, due to the integration of technology in all aspects of daily life, including in education, is of critical importance. Socioeconomic disadvantages in many American communities and school districts are exacerbated by lack of or inadequate access to the Internet. Consequences include academic achievement gaps and lack of technological skills required for the modern workforce, with economically less privileged students and their families at a significant disadvantage. Broadband connectivity is critical for students to meet educational standards; it is also critical for people to work from home, access healthcare services, apply for jobs, order groceries/prescriptions, and fully engage in other daily activities.

Academic disparities between students at the K-12 level with access to high-speed Internet connection and those without access, partly described as the 'homework gap,' has worsened during the Covid-19 pandemic [1], as remote and hybrid learning environments suddenly became at times the only options, creating a new urgency to provide Internet access for underserved areas and to develop innovative curricula that lessen academic and digital achievement gaps. In a study of Michigan schools during the 2020 pandemic, after controlling for socioeconomic and other factors, students with no home access, slow home access, or cell-only access had approximately half a letter grade lower overall GPAs than students with fast home Internet access, that is, the difference between a B- and a B average [1].

Many students in marginalized communities experience the dual burdens of low educational attainment and consequently poor future employment prospects. Because of these challenging circumstances, teachers, school administrators, students, community

members, city officials, and other partners are actively developing inclusive infrastructures to provide Internet access and technology-based curricula to lessen the academic achievement gaps and to provide students from disadvantaged communities with the skills required to effectively participate in the 21st century economy. Many schools, particularly those located in low socioeconomic neighborhoods, are designing ICT-based curricula that enhance their students' digital literacy skills [2].

In 2017, an Internet Backpack pilot project was launched, when Syracuse University researchers demonstrated the Internet Backpack in third-grade classes at the local Van Duyn Elementary School in Syracuse, New York, USA, and connected them to school children in New York City, Liberia, and the Democratic Republic of the Congo (DRC) who were similarly equipped. The Internet Backpack is optimized to bring broadband connectivity to the world's most technologically remote regions, even in 'worst case scenario' circumstances. Its applications in disaster relief and management are established [3], [4]. For example, the Goma Volcano Observatory has relied on an Internet Backpack for mobile emergency connectivity and sensor network monitoring since 2017 [5], [6]. Given current global conditions of the spread of the pandemic and economic recessions, its utility is increasingly relevant, both in remote regions and underserved American communities. Full democratization of Internet access seemed an unattainable goal. However, it is now widely recognized by policymakers and parents to be imperative for educational attainment and job security during and after the Covid-19 pandemic, especially in impoverished households and communities that are systematically affected by a lack of high-speed broadband connectivity [7].

It is possible to quickly increase access, affordably, by utilizing cognitive systems and cyber-physical infrastructure to extend access on a low per-user cost – for example, up to 25 users and 250 devices in schools on the African continent might share the connectivity of one Internet Backpack [7]. The New York City Internet Backpack deployment pilot was also successful, with a high level of cooperation from teachers, who were enthusiastic learners of the backpack technology and optimistic about applying it to their Science curricula. The school children were extremely enthusiastic with the concept, and only disappointed because they could not all immediately take an Internet Backpack home with them [8]. New York City students remain engaged in an ongoing Science-based sustainable urban agriculture project with schools worldwide that have also integrated the use of the backpack into their Science curricula. In this paper, we first discuss technical aspects of the Internet Backpack as a cognitive, cloud to edge cyberphysical system for connectivity and computing, followed by analysis of results of our initial pilot study. This Pace University doctoral study was conducted to evaluate its effect on the learning of elementary school children specifically at the Alchemist Club Studios, at Timothy Dwight PS 33X, in New York City [8].

II. INTERNET BACKPACK: AN INNOVATIVE TECHNOLOGICAL APPROACH

Beginning in 2002, Syracuse University researchers and collaborators, with support from the National Science Foundation's Division of Engineering and Computer and Information Science and Engineering, developed design concepts and applications of a wireless grid mesh or cognitive wireless network, leading to the invention of 'edgware' applications [4], [9], [10]. By 2012, novel cognitive systems for emergency communication across any available frequency were described, leveraging software-defined radio and other technologies in combination with edgware. This modular system was mobile but not fully portable, as it required a car battery to power its power-draining multitude of cognitive radios. The intelligent deployable augmented wireless gateway was therefore never successfully deployed beyond academic trials conducted in cooperation with public safety agencies, reported in prior CogSIMA articles [11], [12]. Within a year of the conclusion of the NSF projects in 2014, this work led to the 2015 invention of the Internet Backpack, which can bring connectivity anywhere, as it is also a cyber-physical system with a microgrid consisting of a foldable solar panel and battery included. A first public demonstration of the Internet Backpack occurred by invitation at a UNICEF-organized 'In Case of Emergency' event at Google San Francisco in 2016, which was followed with a first live deployment to the Goma Volcano Observatory in the Democratic Republic of the Congo in 2017 [5]. These previous trials and further refinement of the innovations incorporated, cyber-physically, into the Internet Backpack contributed to the deployment and trial adoption of two Internet Backpacks by elementary schools in the Bronx and Brooklyn, New York, also beginning in 2017.

Our project approach is novel as it applies the Internet Backpack, a new technological model and cognitive system for mobile and sustainable immediate connectivity, and cloud to edge secure resource-sharing, to strengthen the educational system at a local school district level. Three years after introducing the Internet Backpack in the DRC to the Conflict Zone of North Kivu Province, it remains in use by the Goma Volcano Observatory and the L'Ecole du Cinquantenaire, a local secondary school. Similar first generation (with upgraded edge software, that is, edgware) Internet Backpacks also remain in use in three elementary schools in Brooklyn and the Bronx, New York. The Internet Backpack is at the time of this writing in 2021 in use in approximately one dozen countries and has been subject to prior evaluative research [3], [5], [6]. We theorize that access to Internet Backpacks can significantly accelerate digital transformation within low-income and underserved communities. We expect this deployment in New York City to provide sufficient data and evidence of an innovative socio-technical model that can be expanded, deployed and tested in surrounding local communities and eventually at a national level, to promote very rapid sustainable social and economic change, as compared with alternatives.

The Internet Backpack is a reconfigurable, deployable wireless mesh network that provides cloud-managed mobile edge connectivity solutions to create resource-sharing Wi-Fi hotspots capable of providing up to 25 users, and 250 devices per backpack with a quality Internet experience. Off-grid mesh networks are also supported, including Bluetooth Low Energy (BLE), GoTennas and in some models, LoRaWAN, the Long-Range Low Power Wide Area Network standard supported by the LoRa Alliance and developed by Semtech and/or the IEEE 802.11ah-based Wi-Fi-based Internet of Things sensor data network communication protocol [13], [14]. Other sensor data network options including ZigBee and Sigfox can readily be incorporated as users wish [13], [14]. The backpack's mobility and sustainability provide immediate connectivity, which makes it a unique 'serverless' or 'infrastructureless' cyber-physical solution to limited Internet access in resource-constrained circumstances. We can describe the Internet Backpack as embedding its own cyberinfrastructure or more precisely, cyber-physical infrastructure [15]. Further, the Internet Backpack works cloud to edge across cellular and mesh networks, and in some models, incorporates satellite access, such as is presently available from Inmarsat and in beta from SpaceX; or alternatively, could be configured to work with White Spaces [16]. These options are largely beyond the scope of the Internet Backpack deployments in schools globally at present, which primarily rely on an early commercial 'off the shelf' Internet Backpack LiTE model from Imcon International Inc. which requires only access to an LTE cellular network to create and manage a cloud to edge resource-sharing community, including both connectivity and device access in the cyber-physical bundle offered to up to 25 simultaneous users per pack [17], [18]. As 5G networks become more widely deployed, we anticipate they will be incorporated into the Internet Backpack's cyber-physical infrastructure as a connectivity option as well.



Fig. 1. Internet Backpack for Edge Connectivity
 (Source: Courtesy Imcon International Inc. Used with permission)

III. EFFICACY OF THE INTERNET BACKPACK IN NEW YORK CITY ELEMENTARY SCHOOLS

Internet Backpack education projects to date are typically a collaboration of Syracuse University researchers, Imcon International Inc., and One Planet Education Network (OPEN), a private education provider for schools and students in approximately twelve countries [19]. OPEN creates and manages international STEM education and technology programs and curricula that focus on local sustainable community development. Students and teachers collaborate across borders and cultures on similar community development programs, to which they locally apply the latest ICT technologies. OPEN's objectives are to level the playing field and give equal voice and special opportunities to residents of low-income communities and developing countries, young girls and women, and indigenous peoples of the world. OPEN partners with national governments and the private sector to support education systems by providing teaching material, teacher training and capacity building at government funded primary and secondary schools. MIT Media Labs Responsive Environments, Tidmarsh Living Observatory – Ecosystems Restoration Project and Syracuse University School of Information Studies are among OPEN's strategic research partners [20].

Broadband access affects educational achievements both directly and in combination with other factors. For the 2018-2019 academic year, academic performance in the South Bronx (New York City Geographic District #10 - Bronx), location of Timothy Dwight PS

33X, was below New York State's averages and long-term goals. For the 2018-2019 school year, 70% of students were Hispanic or Latino, 15% were Black or African American, 8% were Asian or Native Hawaiian/Other Pacific Islander, 6% were White, 1% was American Indian and 1% was Multiracial. Other demographic student groups include 22% English language learners, 21% students with disabilities, 84% economically disadvantaged and 16% homeless students [21]. At the elementary school level, 26.5% of students were chronically absent, exceeding the state's rate of 14.6% and the state's long-term goal of 12.8%. Chronic absenteeism was highest among students with disabilities (33.3%), followed by economically disadvantaged (28.2%), Blacks (27.7%) and Hispanic or Latino students (27.2%). English proficiency level (34%) was below the state level (45%) and Mathematics proficiency level (31%) was also below the state level (49%), with proficiencies lowest for male, Black, Hispanic or Latino, students with disabilities, homeless and economically disadvantaged students [21]. Further, proficiencies decline as students graduate to higher grades. These trends are replicated at the state and national levels for disadvantaged students.

We have been involved in multiple projects that aim to determine if improving academic performance, in part because of Internet Backpacks being offered to resource-constrained children, as a form of technological and educational innovation, can more quickly be achieved than options requiring new infrastructure build-outs. A project goal, and in this paper a research question, is to promote information literacy skills by expanding access to Internet connectivity for elementary school students in underserved urban areas. A second goal and research question is whether enhancing Science education for students by improving a Science based curriculum that deploys the Internet Backpack is observable. In addition to an innovative Internet access system, this deployment also includes the provision of educational and training programs, which are critical to motivating and realizing academic improvements [8]. At the time of this writing, teachers and students at New York City, African, Latin American, and Aboriginal Australian elementary schools continue to integrate the backpack in the classroom and after-school learning Science activities.

In 2019, as part of the academic curriculum of the collaborative Internet Backpack education initiative, the students set up and conducted an indoors version of a global sustainable agriculture research experiment underway across the OPEN network of schools. The project allows children attending the three New York City schools to learn and engage with students globally in ways that would not be feasible without their shared experiences as early adopters and adapters of the Internet Backpack. Through their participation in this sustainable agriculture citizen science project, the elementary school children have deployed IoT Internet sensors and Helium Systems Inc. Hotspot Gateway systems to measure and relay soil moisture data, share their data with other students around the world and collaboratively work on data analytics [22]. Helium hotspots incorporate blockchain technologies and cryptocurrencies, but analysis of these aspects of the cyber-physical learning infrastructure and the cognitive systems described here is beyond the scope of this paper [23], [24], [25]. Fig. 2 shows the plants and data collected by students. This experiment is also conducted simultaneously in schools around the world. The schools utilize OPEN's project-based learning curricula programs and have connected through the Internet Backpack to join a series of periodic international events. The schools contribute school/plants test plot data for OPEN's multi-country agricultural sciences experiment. This Internet Backpack project is similar to case studies with schools in Australia, Kenya, Liberia and other countries in growing essential crops. It is part of a multi-country interlinked sensor data network where both students and scientists learn the latest data sciences and data analytics to improve agricultural productivity and economy (community impact education), mitigate pollution, and protect the environment. Based on initial success in deploying the Internet Backpack, these three New York City elementary schools have collaborated with international schools and experts over the course of the 2017-2019 school years.

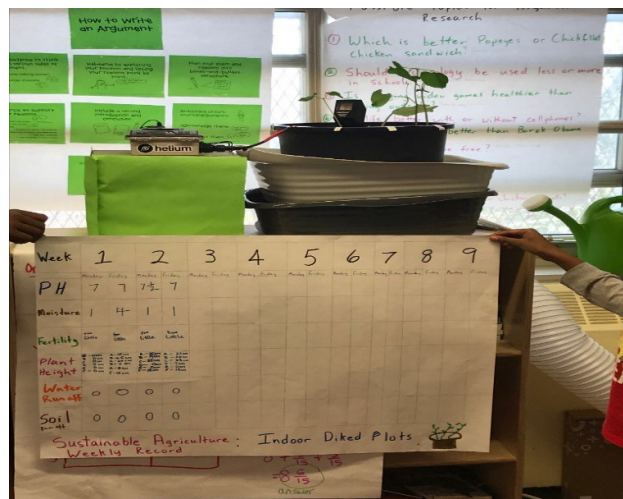


Fig. 2. PS 316 - Students in Ms. Radix and Ms. Do's class share their work and weekly data tables of indoor diked and standard plots. Image courtesy: Dr. Wednaud Ronelus

IV. RESULTS AND DISCUSSION

The Internet Backpack has also been used at the Alchemist Club Studios at Timothy Dwight PS 33X in the Bronx, in New York City. In this project, previous research evaluated the impact of a 3D multi-user web-based educational simulation game on a cohort of fifth grade students' science content mastery [8]. The focus of this study was to find out how immersive educational simulation games can be used to conduct empirical research studies with school children. An important requirement was to make available to students uninterrupted Internet connection. Students were also engaged in writing persuasive in-game reports, solving complex socio-scientific problems and creating digital and physical learning artifacts that are used to assess knowledge transfer. For the researchers, a strengthened Internet connection to allow students to delve into learning more fully with uninterrupted Internet connection was hypothesized to be a significant factor affecting learning outcomes. Thus, the Internet Backpack was anticipated to be an important 'equipment' for the overall project success. To evaluate the learning outcome, various data were collected from students' reports, notes, in-game activities, self-efficacy surveys, reflections, interviews with focus groups, server data, classrooms observation, ethnographic field notes, and pre-test/post-tests information. Seven regular fifth-grade classes participated in this study. Students were randomly placed in these classes. The study sample contained 74 males and 91 females [8].

Table 1 depicts the academic achievement pre-test and post-test mean gain values by study group. An independent samples t-test was used to test a cohort of fifth grade students' science content mastery. The means for the academic achievement pre-test for group A was 6.77 and 5.56 for the control group B on a scale of 0-16. In line with research hypotheses, the means for the academic achievement post-test for group A was 11.04 and 6.41 for group B on a scale of 0-16. The mean gain was 4.27 for group A and 0.85 for group B [8].

Table 1: Achievement Pre-test and Post-test Mean Gain Values by Study Group

Statistic	Pre-test		Post-test	
	Group A	Group B	Group A	Group B
N	90	75	90	75
Mean	6.77	5.56	11.04	6.41
Standard Deviation	3.028	2.195	3.348	2.366
Standard Error Mean	0.319	0.253	0.353	0.273

(Source: Courtesy Dr. Wednaud Ronelus and Pace University)

Results demonstrate statistically significant positive learning experiences with the Internet Backpack, which we partially attribute to uninterrupted Internet connectivity, a scarcity in this neighborhood. The positive experience encourages us to continue our work with deployment of the Internet Backpack in urban STEM education contexts. Given the increasing criticality of Internet access across the US, we expect deployment of Internet Backpacks in underserved schools such as those studied in the Bronx and Brooklyn to also inform and guide similar projects across other schools and communities. We anticipate future expansion of the project to school districts in other highly disadvantaged urban neighborhoods as well as in rural communities where underserved schools and school children are disadvantaged from limited Internet access.

V. CONCLUSION

We provide evidence of the efficacy of the Internet Backpack education pilot project in New York City schools for affecting learning outcomes. The study results indicate providing broadband Internet access immediately improves scientific reasoning and science mastery for underserved students. Building on the successful deployment of Internet Backpacks in schools, community centers, scientific (volcano) observatories and other locations globally over the past few years, more systematic field research and evaluative studies are needed. The evidence to date suggests that academic performance can be enhanced with the deployment of the Internet Backpack. Larger-scale deployment projects and accompanying research on efficacy and impact are ongoing, and additional deployments are proposed. Admittedly, a significant limitation of this project is its narrow scope and focus on short-term, immediate technology-centric solutions to deeply rooted socioeconomic and sociotechnical problems of long-standing and systemic patterns of disadvantage within city limits because of political, socio-economic, and other differences [26], [27].

Our project results warrant expansion and extension of the pilots, the authors conclude. We will continue to collaborate with teachers, school administrators, community residents and public officials to deploy and evaluate the efficacy of Internet Backpacks for rapidly overcoming well-documented academic performance gaps for many school children in underserved communities, partially attributed to below-average access to Internet, and device, and cloud and edge service [26], [27]. Based on these findings,

we propose to create and evaluate instant local and perhaps mobile/pop-up technology centers, where underserved students and community residents can gain access to the Internet, based on the availability and capability of the Internet Backpack and its resources including both connectivity and devices. As appropriate, we plan to extend outreach efforts to other communities and cities. Other researchers and educators are encouraged to seek to replicate this study, and either validate and confirm, or question and correct, or we believe most likely refine, project findings.

To date, we have limited previous deployments to public and shared spaces. However, within homes, other household members share school-provided Wi-Fi hotspots and devices with students. This is understandable given the need but may degrade the service to the point that the students' academic performance (homework completion) is negatively impacted. Thus, in future deployments, it is anticipated that students will be able to check out the backpacks for use at home, using a library loan system. The intelligent edge bandwidth resource management design of the Internet Backpack is especially attractive in these circumstances, to limit bandwidth costs while providing effective educational access. Further, partners at Elijah Stroud Elementary School are developing a project proposal to deploy the Internet Backpack in every school in New York City and to create an IoT network that can be used to collect a broad range of data and metrics. The plan also integrates design of a hub using the backpack in New York City housing projects that will benefit school children who live in these projects. The results of these and similar proposed studies could potentially validate the findings of this pilot study and encourage others to undertake similar projects in other cities, states, and nations. We plan to continue with further empirical work evaluating these expanded projects and controlled studies of this novel model and approach.

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