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RESEARCH ARTICLE

Educational Inequality in Rural and Urban Bangladesh Amid Covid 19: A Multilevel Ecological Analysis Through the Lens of Bronfenbrenner's Ecological Systems Theory

Nipun Naureen[1], Md. Monir[2], Tabassum Nuha[3], Abid Yeasar Shadman[4]

[1,2,4]Lecturer, Department of Economics, Bangladesh University of Professionals Mirpur Cantonment, Dhaka-1216, Bangladesh

[3]Department of Mass Communication and Journalism, Bangladesh University of Professionals, Bangladesh

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***Corresponding Author:**

nipun.naureen@bup.edu.bd

ABSTRACT

This study explores the role of different ecological levels, following the framework of Bronfenbrenner's Ecological Systems Theory, in shaping students' access to digital technology that ultimately affected their academic achievement during the COVID-19 pandemic in Bangladesh. This study examines rural–urban differences across digital access, social determinants of health, and supportive institutional environment using data from 372 secondary school students. The study tested seven ecological theory-based hypotheses using quantitative methods (logistic and multinomial regression and chi-square analysis). Results showed substantial macrosystem-level structural inequalities in device ownership and online class attendance between urban and rural students. The exosystem also influenced digital access, with students from wealthier families and those with better-educated parents having substantially better access. Microsystem factors such as ownership of a device had a strong predictive value for student's online class participation and was correlated with less academic decline. Furthermore, the chronosystem was also at play as student's facing mental and physical health problems experienced poorer academic outcomes. Some of the negative impacts were cushioned due to institutional support, in particular, financial subsidies. The findings of this research affirm the complex, multi-layered nature of educational inequality during the pandemic, and highlight the need for targeted multi-level policy measures to close social and geographical gaps in digital education access.

INTRODUCTION

The COVID-19 pandemic has caused one of the largest disruptions of education systems in history, necessitating an unprecedented transition from in-person instruction to immediate remote online learning (Sunita, 2020). Although this transition maintained academic continuity for the majority, however, it also highlighted overdue access inequality in education (UNESCO, 2020). However, the difference in socioeconomic factors and digital access across regions turned out to be one of the key determinants of whether students could access education during school closures or not. This was especially challenging for rural students who had to struggle with limited access to technological infrastructure, parental support and institutional guidance as compared to their urban peers (Graves et al., 2021; Yanlin et al., 2024). In particular, the mere difference in infrastructure cannot explain how student's surrounding environment limited student technological access with educational outcomes (Saleh et al., 2023). To better address these disparities, and to understand how different factors leading to the disparity interplay, Bronfenbrenner's Ecological Systems Theory provides a comprehensive framework that emphasize the interconnectedness of multiple layers of a student's environment (including family, school, community, and larger societal structures) that influence development and learning. Using the Ecological Systems Theory (EST), the complex

interactions across multiple ecological levels such as the microsystem, mesosystem, ecosystem, macrosystem, and chronosystem during a global pandemic can be understood more holistically.

While authorities at national and institutional levels sought to facilitate digital learning to overcome educational loss of students during the COVID-19 pandemic, substantial gaps in education remained, especially between rural and urban students in Bangladesh (Liu, 2021). Rural students had more limited access to digital devices in terms of accessibility and availability, reducing their attendance in online classes and consequently lowering their performance (Arefin et al., 2023; Liu, 2021). In addition, the pandemic context magnified psychological and health-related stressors (Hoque et al., 2021). Student's experience also varied depending on parental occupation, household income, and educational background (Aman et al., 2019).

Although previous studies have investigated the phenomenon of digital divide or academic performance separately, only a few research globally and much lesser in the context of Bangladesh, systematically examined how various layers of environment as conceptualized in Bronfenbrenner' Ecological Systems Theory converged to restrict educational access and achievement. It is therefore essential to examine the interaction between micro-level experiences (device ownership, parental involvement, etc.) and macro-level structures (geographical inequality, institutional policy, etc.) to understand how this shapes students' learning trajectories. Thus, the present research conducted a theoretically grounded ecological framework - providing a thorough account of the multifactorial and multifaceted nature of students' digital access, experience and academic outcomes during COVID-19.

Research Objectives

1. To explore the relationship between school location (rural versus urban) and students' access to digital means during the COVID-19 pandemic.
2. To examine the influence of students' socioeconomic status (parents' occupation; income) on their accessibility and availability of digital learning resources.
3. To examine the relationship between digital accessibility (device ownership, internet access) and students' participation in online classes.
4. To explore whether restricted digital access was responsible for decline in academic performance during the period of COVID-19.
5. To assess the influence of physical and mental health problems for students' academic performance in times of the pandemic.
6. To determine whether institutional support (e.g., subsidies or assistance in the school) mediate the negative effect of digital divide.
7. To use Bronfenbrenner's Ecological Model in explaining the multiple levels of influence on education inequities in rural urban context during COVID-19.

Research Hypotheses

The research objectives are listed in table 1.

Table 1. Hypotheses developed through the integration of EST

	Hypothesis	**Ecological Level**
H1	The disparity in digital access (devices, internet) for students in rural areas compared to urban was substantial	Macrosystem
H2	Lower socioeconomic status (family income and parents' occupation) is associated with lower digital access and reduced participation in online classes.	Ecosystem
H3	Students who had relatively higher digital access (in terms of device ownership and internet availability) were more likely to participate in online classes.	Microsystem
H4	Students with better digital access experienced less academic decline during the pandemic.	Microsystem

H5	Those who experienced physical or mental health difficulties during the pandemic was more likely to show academic performance decline.	Chronosystem
H6	The digital divide impacted less adversely on students who had received institutional support (subsidies).	Mesosystem
H7	There exists statistically significant rural urban disparity in the variables that constitute the different levels of the Bronfenbrenner's Ecological Model.	Macrosystem

Theoretical Framework: Bronfenbrenner's Ecological Systems Theory

Bronfenbrenner's Ecological Systems Theory (1979) constitutes a comprehensive summary of the literature spanning decades that addresses the fundamental mechanisms governing life-span development of an individual. Contrary to most other recent theories, Bronfenbrenner did not condition development on a particular domain such as social relations, cognition or biological aspects. Instead, Bronfenbrenner pursued a scientific approach that centered on the interaction between processes and the contextual variability of these processes. The Ecological Systems Theory (EST) by Bronfenbrenner (1979) describes human development in terms of the interdependent systems of relationships that constitute the environment that surrounds an individual. The structures are seen as nested, one inside the other: the microsystem, mesosystem, exosystem, macrosystem, and the chronosystem. Being interconnected, the influence of one system on human development and behavior rely on its relationship existing with all four systems. The theory provides a multi-dimensional and interactive method to reveal some of the more intricate factors of inequitable experiences in education during a humanitarian crisis like COVID-19.

The Microsystem

This microsystem is made up of environments where a student has regular and direct contact, for example, the student's home. The microsystem became more significant during the COVID-19 pandemic because following the lockdown, students stayed home for a long period of time. In rural settings, a great number of students were subject to severe constraints in the home, such as, sharing living spaces with other siblings, lack of personal study spaces and the lack of parental support (a feature of low literacy and poor economic circumstances). These inconveniences severely compromised the extent to which the rural students were able to access the online learning resources. Urban students, however, were more likely to have favorable study environment, personal digital devices, internet, and family support.

The Mesosystem

The mesosystem involves the interconnections between two or more microsystems in the student's life. For example, the connection between the home and school. During COVID-19, such engagements proved to be instrumental for assuring students' educational continuity. The decrease in academic performance of those with institutional assistance was lower. Communication with school during the crisis was continued through email, WhatsApp groups and school apps. As a result, urban students had easier transition to online education. Besides, urban parents were digitally more literate and more involved in the education of their children. Rural settings, in contrast, often presented instances of mesosystem failure. Teachers had little or no training to rely on, and the school system in many rural areas was ill-equipped to provide technology support to stay in contact with students, and parents. Many rural parents had not been using digital tools themselves, so it was hard for them to help their children. These mesosystem links had been disrupted with serious implications for student motivation and access to learning resources and overall educational participation.

The Ecosystem

Ecosystem settings are those that do not have direct contact with the student, yet impact on his development. Among these are parents' job, measures taken by the government or institution, resources within the community as well as access to digital devices. A significant number of families, in both rural and urban setting, experiences job loss or income reduction during the pandemic. In urban areas, the situation was slightly better considering the fact that even though there were job

losses, there was commonly more access to support from government or organizations: for instance, provision of loans or subsidy from educational institutions to students so that they can purchase devices such as smartphone and laptops, the community Wi-Fi or the donations from NGOs and local entities. Many rural families did not even have access to newspapers, television, hardly the internet. This inequality in these indirect effects made a strong contribution to the online education.

The Macrosystem

The macrosystem refers to larger societal and cultural values, norms that impact on the student's environment. The macrosystem during the pandemic was comprised of the government focus on digital education, attitudes in society about online learning and geography and class based structural inequalities.

In most nations, policies driving development have favoured cities for infrastructure, internet connectivity and education investments. Consequently, urban students were already more accustomed to the new learning style when education went online. Rural areas that did not have a robust digital infrastructure were further excluded.

The Chronosystem

The chronosystem includes life events that can have either a positive or negative influence on the individual and his surrounding environment. The time of the pandemic, the stress on students and families, both mental and physical, all belong to this layer. At the initial stages, many inequalities seemed manageable, however, during the prolonged lockdown, inequalities rather intensified. A greater number of rural students experienced long-lasting learning loss, greater dropout rates and mental distress due to sustained exclusion from effective education. Health also belongs to the chronosystem. Many students complained of physical health challenges stemming from too much screen time, including eye strain and postural problems. Additionally, mental health issues such as anger, depression, anxiety, worsened due to prolonged isolation and academic disconnection. The impact was stronger for students with restricted social support networks, such as rural students.

LITERATURE REVIEW

The COVID-19 pandemic has exposed and exacerbated inequalities in global education systems, especially on the front of geography, socio economic status, and technological infrastructure. Family background, socioeconomic factors such as parental education, profession, and income, has long been known to be major factors influencing students' educational performance and the digital divide, especially between urban and rural areas. An increasing number of literatures has attempted to explore these differences, utilizing comprehensive frameworks like the Bronfenbrenner's Ecological Systems Theory, offering increasingly explicit perspectives to the problem.

(Lareau, 1987) indicated that the primary determiner of educational opportunity was family background while (Manstead, 2018) characterized higher social class as possessing more income, higher education, and better material resources. All these directly impact academic success and the ability to access learning tools. Past research has indicated that parent's education capability is a significant predictor of parent's involvement and assistance in their children's education (Gooding, 2001), less-educated parents tend to pass their responsibility to teachers and school (Li & Ranieri, 2013). (Nelson, 2009) found that parents who did not attain college education, tend to have less awareness of the socioeconomic merits of their children's education. During COVID-19, students from households with a higher level of education had a higher involvement with formal educational activities and online resources as compared to their counterparts (Aman et al., 2019). They imply having secure financial resources, which are closely linked to the level of education (Drajeaa & O'Sullivan, 2014), including digital facilities, emotional health, and other factors that ensure a stable learning environment. Parental investment also significantly correlates with academic self-concept among children (Ho & Kwong, 2013), reaffirming the microsystemic synergy of families in Bronfenbrenner's theory.

The COVID-19 induced closure of schools in more than 181 countries affected more than 1.5 billion students, with growing dependence on e-learning (UNESCO, 2020). Nonetheless, students of the rural still reported lower internet-connected devices and other amenities (Graves et al., 2021; Yanlin et al., 2024) found that urban students consistently scored better in most aspects of online learning.

Their research exhibited lower level of engagement and satisfaction in online education among rural leaners. Findings from (Arefin et al., 2023) suggests that online learning in rural areas is poorly resourced and hampered by problems such as unreliable internet, and limited ICT tools, and interruptions in electricity. Socio-economic disparity in home environment, lack of access to information technology, low understanding of online learning in parents, and issues in interpersonal relationships in families added to these challenges (Romero-Hall, 2021; Rundel et al., 2021).

The digital inequality has been thought of across three levels: access, mastery of use and tangible benefit (Ragnedda & Laura Ruiu, 2017). The excluded are educationally and socially disadvantaged at every level (Aissaoui, 2022). Likewise, (Andrew et al., 2018) indicated that digital inclusion status of the students was closely related to students' attitude towards technology and digital competence; (Ullah, 2020) has shown that elite groups experienced disproportionate access to digital services, which excluded poorer students to have equitable participation in the remote learning.

Besides the digital inequality issue, the mental and physical health of students was also compromised due to the pandemic. For instance, 82.5% of undergraduates suffered from mild to borderline moderate to severe anxiety attributed to the e-learning limitations in Bangladesh (Hoque et al., 2021). In India, isolation and uncertainty, along with excessive screen time and lack of socializing, have also led to anxiety and emotional disturbance (Kochhar et al., 2020; Moitra & Madan, 2022; Wares Hallee & Choudhary, 2024). In Malaysia, (Etajuri et al., 2022; Sundarasen et al., 2020; Sy-Cherng Woon et al., 2021) found that frustration from loss of daily routine with lockdowns resulted in continuous overall stress. In Italy, (Servidio et al., 2021) and in China (Chen et al., 2021) found that excessive internet use and internet addiction are associated with mental distress. This chronosystemic impact of COVID-19 on development and education is especially apparent in these findings.

Although some studies have employed Bronfenbrenner's ecological lens to examine digital learning, online education and digital divide during COVID-19 in other countries (Amali et al., 2023; Bratanoto et al., 2022; Fulantelli et al., 2021), so far, none has employed Bronfenbrenner's ecological system theory to conduct similar research in Bangladesh. The ecological system model, however, has already been adopted for researching many social and development related issues. (Arafat & Saleem, 2025) used ecological system model to study suicide and suicide prevention in Bangladesh, (Hossain & Uddin, 1 C.E.) used ecological system model to explore relationships between unhealthy physical environment in schools and infectious disease transmission among students, (Rahman & Rahman, 2025) examined the quality of a child's environment and its impact on children's resilience and motivation, (Kalam et al., 2025) explored the model as conceptual framework for child marriage drivers.

This literature review shows that the home environment, access to digital and mobile technology, parent background and health, as well as institutional support, were repeatedly associated with student participation and performance in the pandemic time education and rural-urban divide. Theoretically, there is a gap in synthesizing these findings through an ecological systems lens, especially in case Bangladesh. This work provides the first empirical test of an ecological model that integrates these disparate strands of literature—home environment, digital access, aspects of socioeconomic disadvantage, health, and institutional mechanisms—across multiple levels of Bronfenbrenner's ecological model and thereby fills an important literature gap.

METHODOLOGY

This study aimed to examine the exacerbation of the digital divide between urban and rural secondary school students in Bangladesh during the rapid shift to online education. With this view in mind, the researchers employed a pragmatic philosophical method, engaging fundamentals of both positivism and interpretivism to comprehend the intricate dynamics influencing students' digital access to education and academic performance. The epistemological basis of critical realism is utilized to recognize an objective reality while acknowledging the socially perceived nature of knowledge in educational context during a crisis. The research design follows a cross-sectional quantitative approach. Data was collected using structured questionnaire, students' responses to online surveys and in-depth interviews were used as primary data. Data was collected from students across all eight administrative divisions in Bangladesh. A non-probability convenience sampling method was employed due to practical constraints and limited access to comprehensive datasets.

Both offline and online surveys were conducted in the rural regions and only online survey were conducted in the urban regions. Use of identical questionnaires ensured consistency across platforms. The questionnaire consisted of 33 questions on topics including socio-economic condition, educational background of parents, home environment, access to digital resources (devices, internet access, and platforms), receipt of subsidies or other help, and health challenges related to online learning (both physical and mental). A total of 406 observations were taken and after cleaning 372 were used for analysis. 180 qualitative interviews were conducted over the phone, employing a purposive sampling method to seek out viewpoints outside of the quantitative data. Data collection was ensured ethically accordingly. Participants provided informed consent prior to participation, and confidentiality and anonymity were maintained.

Both descriptive and inferential statistical techniques were employed for data analysis. Descriptive statistics including frequencies, means, and standard deviations was used to analyse the characteristics of the sample and to observe the distribution of key variables. Inferential statistics such as t-tests, chi-square tests, and multiple regression analyses were used to test the hypotheses and explore associations among variables.

RESULTS

Hypothesis 1: Students in rural areas had significantly less digital access (devices, internet) than urban students. (Macrosystem)

An independent samples t-test was performed, comparing device ownership of rural and urban students, to investigate if access to digital devices differed according to student location. Based on these statistics, the differences in digital device ownership were statistically significant, $t(370) = -3.21$, $p =. 0015$. In rural students, the digital device ownership rate was lower ($M = 0.85$, $SD = 0.36$, mean difference = 9.7%), compared to urban students ($M = 0.95$, $SD = 0.22$). Such evidence points to an urban-rural (and, therefore, geographical and socio-spatial) gap in the availability of digital tools, underscoring that, in the rural areas, many students lacked the means to take part in online learning. The binary logistic regression results, performed to examine the association between student location and digital device ownership, also reveal that urban students were much more likely to possess a digital device than rural students ($\beta = 1.16$, $SE = 0.38$, $p =. 002$). More specifically, Urban students had higher odds of device ownership 3.2 times higher than those in rural areas ($OR = 3.20$).

Hypothesis 2: Lower socioeconomic status (measured by income and parents' occupation) is associated with lower digital access and reduced participation in online classes. (Ecosystem)

A binary logistic regression was performed to assess the effect of monthly household income on digital device ownership among students. The model was significant, $\chi^2(3, N = 372) = 35.66$, $p <.001$) indicating that income level was a significant predictor of device ownership ($p=0.001$). Students from higher income households were far more likely to have possession of digital devices than students from households with monthly income below 10,000 BDT (reference category). In other words, students falling under the 10,000 - 25,000 BDT income group were 4.40 greater odds of owning a device ($\beta = 1.48$, $p =. 03$), whereas those belonging to income range 25,001–50,000 BDT group had 15.07 times higher odds ($\beta = 2.71$, $p <.001$), and students who belonged to families to earn more than 50,000 BDT were found to have 24.00 times higher odds ($\beta = 3.18$, $p <. 001$) to own digital devices. These findings illustrate the significant positive association between ownership of digital learning resources and socioeconomic status.

A chi-square test for independence was performed to determine whether the device ownership would be dependent on the mother's occupation. This association was not statistically significant, $\chi^2(1, N = 372) = 1.73$; $p = 0.189$. Of those whose mothers were housewives, 87.1% owned digital devices and 12.9% did not. Likewise, among students whose mothers were in service, 95.2% own devices and 4.8% do not own devices. Students with working mothers had a higher percentage of device ownership, albeit not statistically significant.

A chi-square test of independence was performed to determine whether the students access to digital device for online classes was associated with the educational qualification of their father. These outcomes demonstrated a very high association between these two factors, $\chi^2(1, N = 372) =$

12.73, $p < 0.001$. Of students whose fathers had a graduate level education - their digital device ownership was 95.44% - versus 84.73% of those whose fathers had a higher secondary education and below. In contrast, lack of device ownership was more common among students with less-educated fathers (15.27%) than among their counterparts whose fathers had more education (4.56%). This implies that student's digital access is strongly linked to parental educational background - especially paternal.

The association of mothers' educational qualification with students accessing digital device for online learning during COVID-19 pandemic was explored using a Pearson Chi-square test. Results of the test indicated a significant association, $\chi^2(1, N = 372) = 8.65$, $p = 0.003$. For example, 96.07 per cent of students whose mothers were graduates owned a digital device as against only 87.63 per cent of students whose mothers were higher secondary graduates. This indicated that students with less educated mothers were also overrepresented among those without access as 77.42% of the students for whom no device was available would have a mother whose highest educational level was higher secondary.

In support of Hypothesis 2, higher maternal education is significantly associated with the likelihood that students access to a digital learning tool. Even a brief glimpse of the results can be sufficient to reiterate some aspects of the microsystem and exosystem of Bronfenbrenner's Ecological Systems Theory, where background parental factors —especially mother's learning environment of the students– is an extremely importance factor predicting students learning.

Hypothesis 3: Students with greater digital access (device ownership and internet availability) were more likely to attend online classes. (Microsystem)

Using binary logistic regression, we explored the association of access to digital devices with participation in online classes of students in COVID-19 pandemic. The model was significant, $\chi^2(1, N = 372) = 39.27$, $p < 0.001$, suggesting device ownership is a significant factor when predicting online class attendance.

The log-odds coefficient for a student who owned a digital device, for example, was 2.73 ($p < 0.001$), suggesting these students were much more likely to engage in online classes. If a participant had access to a digital device, this means the odds of attending online classes were 15.33 times higher ($e^{2.73} \approx 15.33$) than if the participant did not have such access. Additionally, the Pearson Chi-square test was statistically significant, $\chi^2(1, N = 372) = 63.19$, $p < 0.001$, suggesting a very strong association between device ownership and the engagement in online learning. Of the students with devices 95.5% attended online classes, while that proportion plummeted to 42.1% among those without. This close correlation emphasizes the essential influence of digital access—an exosystem level determining factor in Bronfenbrenner—on students furthering their learning as the COVID-19 pandemic unfolded. According to these results a student who was not provided a device was more than 50% less likely to attend their online classes, highlighting the vital importance of digital access during pandemic-related disruptions and the need for digital access and equity in general.

Hypothesis 4: Students with better digital access experienced less academic decline during the pandemic. (Microsystem)

A Pearson Chi-square test was used to examine whether ownership of a digital device (own device vs. someone else's) was associated with students' self-reported academic result during online classes. Results revealed a near-statistically significant association, $\chi^2(1, N = 370) = 3.56$, $p = 0.059$, as measured by the test. Of the students who owned their own device, 44.4% reported academic deterioration while 55.6% of respondents using someone else's device reported deterioration in their academic results. Such findings therefore suggest that the ownership of devices by the student may provide a more stable and robust learning environment, particularly as students with devices owned by others are more likely to have academic performance deterioration. This is consistent with Bronfenbrenner microsystem view of the immediate setting that taps into the academic outcomes.

As these results suggest that students using devices owned by other people were more at risk of academic deterioration than their peers with personal devices, it supports the notion that own-device ownership may offer a more stable learning environment. This reflects Bronfenbrenner's perspective at the microsystem with the emphasis on the immediate environment and academic results.

Hypothesis 5: Those who experienced physical or mental health difficulties during the pandemic was more likely to show academic performance decline. (Chronosystem)

Chi-square analyses showed significant associations between academic result deterioration during the transition to online learning due to the pandemic and mental and physical health challenges. While testing to investigate if students that experienced mental health issues during distance learning reported a deterioration of academic performance in the COVID-19 pandemic, we found a significant association, $\chi^2(1, N = 372) = 6.92$, $p = 0.009$. Of those who reported mental health problems (anxiety, depression, and stress), 74·53% reported that their academic results had worsened, compared with 61·61% of students who had no mental health issues. By contrast, students who had no mental health challenges tended to describe stable academic outcomes. This finding suggests a notable role for mental health challenges in depressing academic performance during online learning intervals. This underscores the need to consider psychological wellbeing as part of the microsystem and mesosystem level influences on academic outcomes, consistent with Bronfenbrenner's Ecological Systems Theory.

Similarly, students who had physical health problems (e.g., headache, eye strain, fatigue) reported much higher rates of academic decline (75.2% vs. 45.5%, $\chi^2(1) = 16.79$, $p <. 001$). Of the students suffering from physical problems, 75.1 percent had a decline in academic results when compared to only 54.5 percent of students in the survey who did not report having physical problems. Stable academic outcomes were more common among students without physical difficulties.

Under Bronfenbrenner's chronosystem, these results suggest that ecological systems were particularly threatening to students through multiple levels of systems because the COVID-19 pandemic was not only a disruptive event but a lasting and prolonged event that served to highlight students' vulnerability. Long-term online learning expanded screen time, isolation (social and physical), and uncertainty, with cumulative impacts resulting in long-term stress and related health decline over time. These results provide robust evidence that having physical health problems during the online classes played a significant role in worsening academic performance. This highlights that students' health conditions as placed in the microsystem factors affecting educational outcomes as per Bronfenbrenner Ecological Systems Theory.

Hypothesis 6: The digital divide impacted less adversely on students who had received institutional support (subsidies). (Mesosystem)

To examine the relationship between the two types of institutional support (mental health and financial subsidy) and academic result deterioration during online learning, two chi-square tests were performed. Academic result deterioration was not significantly associated with support from mental health services from educational institutions, $\chi^2(1, N = 372) = 0.43$, $p = .511$. Those who did reach out were only marginally (4.4 percent) less likely to claim their academics had suffered (60.3 percent vs. 55.9 percent). This could imply either that mental health services where present were not, in fact, appropriate, effective, or timely enough to reduce academic impact.

In contrast, students getting financial subsidies or institutional support had a much better academic outcome, χ^2 $(1, N = 372) = 3.95$, $p =. 047$. Only 36.4% of students who received financial assistance, for instance, experienced a decline in academic performance, compared with 58% for students who did not. Logistic regression analysis reveals that, students who received a financial subsidy from their institution were approximately 2.4 times more likely to report 'no deterioration' in their academic results than students who did not receive such support (OR:2.43, $p =. 05$), indicating financial support may mitigate the worsening of the outcome during online classes.

This suggests that financial support might have protected students against stressors (limits to digital access, family economic pressure, etc.) that harmed academic success. These results suggest that the ecosystem (institutional structures and resources) is playing a role in students' educational resilience from an ecological systems perspective.

H7: There exists statistically significant rural urban disparity in the variables that constitute the different levels of the Bronfenbrenner's Ecological Model. (Macrosystem)

This hypothesis seeks to validate the assumption that a student's geographical location (rural vs. urban) affects the main dimensions of his or her ecological environment — availability and

accessibility of digital devices, perception of academic deterioration (microsystem), parental occupation/education, monthly income, expenditure on education (exosystem), physical and mental health problems (chronosystem), and institutional support (mesosystem).

Using multinomial logistic regression, the results also found an association between students' location (urban vs. rural) and reported (self-reported) household monthly income categories. The model as a whole was statistically significant, $\chi^2(3, N = 372) = 100.81$, p <. 001, showing that student location was a strong predictor of income classification. The highest income group (Above 50,000 BDT) was set as the reference category, and the results displayed significant negative correlations between the students from urban areas and the odds of belonging to lower income groups. Specifically, urban students were: (i) 96% less likely to fall in the "Below 10,000 BDT" category (β =-4.04, SE = 0.58, p <. 001), (ii) 93% less likely to be in the "10,000–25,000 BDT" group (β = -2.64, SE = 0.38, p < .001), and (iii) 84% less likely to be in the "25,001–50,000 BDT" group (β = -1.83, SE = 0.36, p < .001). When referenced against the 'Above 50,000 BDT' reference group. These results illustrate a clear relationship between geography and income (and therefore, in part, socioeconomic status), with more rural students in increasingly lower income bands as compared to their non-rural peers.

Multinomial logistic regression was used to assess the association of location of student with the occupation of the mother. The overall model was significant, χ^2 (1, N = 372) = 10.99, p =. 0009, suggesting a good association between the two. With "Housewife" as the reference category, it was significantly more likely for students who lived in urban area to have working mothers (β = 0.97, p =. 002) as compared to rural students. It follows that a larger proportion of urban students have their mothers in service. The result accounts for the differences in family social and occupational structure at different areas.

Multinomial logistic regression was conducted to examine the association of student location and father's education level. The model was statistically significant, $\chi^2(1, N = 372) = 48.78$, p < 0.001, suggesting that student location is a significant predictor of fathers' education. In particular, students living in urban areas were significantly less likely to have fathers with only higher secondary level education or below, number of urban fathers who obtained graduation or higher education was much higher (β = –1.62, SE = 0.24, z = –6.79, p < 0.001). The odds of having a less-educated father for an urban student were substantially lower, further reflecting the urban-rural disparity in parental education.

Another multinomial logistic regression was conducted to assess the effect of location of student on the odds of mother having graduate-level education as compared to higher secondary or below. The model was statistically significant, $\chi^2(1, N = 372) = 45.77$, p < 0.001, and can be interpreted as location being a significant predictor of the level of education for the mother. In fact, students from urban were much more likely than those from rural to have mothers with graduate or other higher education (β = 1.60, SE = 0.25, z = 6.36, p < 0.001). A similar trend of positive association of higher Maternal education with urban population points to possible socio-economic differences between rural and urban student populations.

Another logistic regression was conducted to examine the disparity between rural – urban students in terms of financial investment on education as measured by monthly education expenditure. Monthly educational spending differed significantly by student geographical location ($\chi^2(2) = 17.84$, p = 0.0001). Specifically, urban students were much more likely than rural students to spend more on education. Relative to spending 3,000 taka or less on a monthly basis (reference category), urban students had higher odds of spending 3,001–5,000 Taka (β = 0.74, SE = 0.30, p = 0.015) and above 5,000 Taka (β = 1.23, SE = 0.33, p < 0.001) on education. The results indicate a substantial urban-rural difference in financial investment on education.

A logistic regression indicated that online class attendance was significantly predicted by a student's location, χ^2 (1, N = 372) = 30.39, p <. 001. Urban dwelling students were over seven times more likely than their rural counterparts to participate in online classes (OR = 7.25, 95% CI [3.39, 15.52], p <. 001). These finding demonstrate significant urban–rural gaps in digital access during the pandemic, aligned with macrosystem-level effects as per Bronfenbrenner's Ecological Systems Theory. This highlights geographic differences in digital access during school closures.

The results are in line with Bronfenbrenner's Ecological Systems Theory, specifically the macrosystem, defined by variations in structural features such as infrastructure and technology, whereby these differences between urban and rural settings had direct repercussions on the educational continuity of the student population due to the pandemic.

Logistic regression analysis indicated that self-reported academic result deterioration due to online classes was to be significantly predicted by student location, $Chi^2(1, N=372) = 7.75$, $p = .005$. Relative to their rural peers, odds of reporting deterioration were greater for urban students (OR = 1.88, 95% CI [1.20, 2.96], $p = .006$). However, despite urban students being more digitally connected, this finding suggests that academic pressures and online learning environments experienced in urban contexts may have also led these students to perceive that their academic decline may have been worse than their peers. Moreover, as the result deterioration perception is subjective, urban students might feel they had greater decline because of the existence of comparatively higher expectation from the urban families from their children as they spend higher on education expenditure and have greater access to digital education. The outcomes indicate some more complex interactions of the mesosystem and macrosystem as outlined in Bronfenbrenner's framework.

As for health-related consequences, physical health problems did not significantly vary by geographical location ($p = 0.861$). In contrast, a statistically significant mental health outcomes difference was found in that urban students were more likely than rural students to have more favorable psychological well-being during COVID-19 ($\beta = 0.687$, $p = 0.006$). It could be the case that urban settlements are associated with better mental wellbeing because of broader systems of social provision, access to resources, or learning opportunities for adaptation.

In summary, all of these results together represent the broad range in disparity between rural and urban students in their socioeconomics, financial investment of their education, health and wellness resilience to balance development and prosper in education.

Table 2. Summary of Key Results

Analysis	**Variable(s)**	**Findings**	**p-value**
T-test	Device Ownership by Student Location	Urban (M = 0.948) > Rural (M = 0.851)	0.0015
Logistic Regression	Device Ownership by Monthly Income 10K–25K: OR ≈ 4.40 25K–50K: OR ≈ 15.06 Above 50K: OR ≈ 24.02	Increasing income significantly increases likelihood of ownership	< 0.001
Chi-square Test	Device Ownership × Mother's Occupation	Not significant	0.189
Chi-square Test	Device Ownership × Father's Education	Significant; more devices among children of graduates	< 0.001
Chi-square Test	Device Ownership × Mother's Education	Significant; more devices among children of educated mothers	0.003
Logistic Regression	Online Class Participation by Device Ownership	Strong positive association	< 0.001
Chi-square Test	Online Class Participation × Device Ownership	Significant association	< 0.001
Chi-square Test	Result Deterioration × Device Ownership	Small but significant	0.040
Chi-square Test	Result Deterioration × Device Ownership Source	Borderline significance	0.050
Chi-square Test	Result Deterioration × Physical Problems	Strong association: physical issues linked with deterioration	< 0.001
Chi-square Test	Result deterioration × Mental health issues	Significant; Students with mental health issues had significantly higher deterioration in academic results	0.009

Chi-square Test	Result deterioration × Institutional mental health support	No significant relationship	0.511
Chi-square Test	Result deterioration × Subsidy received	Significant relationship; students not receiving subsidy more likely to report deterioration	0.047
Logistic Regression	Result deterioration ~ Subsidy + Mental health support	Subsidy showed marginal positive association (OR ≈ 2.44)	0.051
Logistic Regression	Result deterioration ~ Student location	Urban students had higher odds of result deterioration	0.006
Logistic Regression	Online class participation ~ Student location	Urban students significantly more likely to attend online classes	< 0.001
Logistic Regression	Monthly income ~ Student location	Urban students significantly less likely to be in lower income groups	All p < 0.001
Logistic Regression	Mother's occupation ~ Student location	Urban students more likely to have working mothers	0.002
Logistic Regression	Father's education ~ Student location	Urban students more likely to have higher educated fathers	< 0.001
Logistic Regression	Mother's education ~ Student location	Urban students more likely to have graduate mothers	< 0.001
Logistic Regression	Monthly education expenditure ~ Student location	Urban students spent significantly more	All p < 0.015
Logistic Regression	Mental health issues ~ Student location	Urban students more likely to report mental health issues	0.006
Logistic Regression	Physical health issues ~ Student location	No significant difference	0.861
Logistic Regression	Subsidy received ~ Student location	Urban students less likely to receive subsidy (not significant)	0.077

DISCUSSION

This study aimed to explore the relationship among the different layers of Bronfenbrenner's Ecological Systems Theory, which include the microsystem, mesosystem, ecosystem, macrosystem, and chronosystem, in relation to students' digital access and academic outcomes resulting from the COVID-19 pandemic. Not only did the findings substantiate the utility of this theory to explain educational inequalities, but they also provided compelling evidence regarding the differential experiences of rural and urban students in Bangladesh.

Microsystem: Family, Immediate Environment, and Academic Outcomes

The difference with respect to parent education and occupation (hypothesis 2) further highlighted this disparity. Ownership of digital devices among students whose fathers had a graduate level education was substantially higher (95.44%) than among students whose fathers had only completed higher secondary schooling (84.73%). Similar trends were observed for maternal education and maternal occupation. This underlines the importance of familial educational capital for a conducive learning environment, which is in line with the basic assertion by Bronfenbrenner that developmental outcomes are mainly defined by immediate environment of the microsystem (such as parental involvement and availability of resources).

Urban students tended toward being from higher income households with higher monthly education spending. Those patterns are indicative of larger ecosystem inequities that dictate which resources are accessible to students via parental occupation and family wealth contexts. Furthermore, in keeping with the role of ecosystem influences, Hypothesis 7 indicated also that urban students were at least 3.6 times more likely than non-urban students to have had graduate-level parents and working mothers.

Then, the presence of devices predicted online class participation directly (Hypothesis 3), with 95.5% of students with devices but only 42.1% without devices attending online classes. Which emphasizes the immediate need for localized and accessible material resources, such as a digital learning device, to ensure continuity in learning during a disruption such as a pandemic.

Mesosystem: Institutional Assistance and Interconnections

Through analysing mesosystem, we find that a potential solution for minimizing the impact of the digital divide (Hypotheses 6) is institutional support (e.g., financial subsidies or mental health services). The results demonstrated that financial aid was significantly related to students' academic success: just 36.4% of supported students showed signs of academic decline, while 58% of unsupported students did. It found that students receiving subsidies were 2.4 times more likely to say their academic performance had been stable.

Support from institutions in mental health contributed little to academic stability, indicating the possible ineffectiveness, or poor delivery of the services. These results highlight how the mesosystem plays an important role in either exacerbating or counteracting the academic achievement gap contingent on the interplay between institutional resources and the home environment of the student.

Ecosystem: Availability and Access to Resources, Environmental Influences

The ecosystem refers to the factors that do not involve the student directly but indirectly influence their development, such as family income, parents' occupation, and education expenditure. A few results were observed at the ecosystem level. Hypothesis 1 was confirmed: students from rural background had much less access to digital devices compared to their urban peers. Urban students had over three times the odds of owning a digital device. Such disparity in access to digital device signals an inequitable gap in the learning environment in geographical context. A strong positive association was found between household income and device ownership confirming Hypothesis 2. The availability of access to digital devices was significantly higher for students from higher income groups, confirming the idea that structural inequalities of economic capital are still an important factor explaining differences in educational opportunities. There was moderate support for hypothesis 4, which hypothesized that students with greater digital access would experience a smaller academic decline. Result deterioration rates were lower (44.4%) for students with their own device compared to students who used another person's device (55.6%).

Chronosystem: Health Crises and Their Long-Term Effects

Hypothesis 5, indicating that health challenges are related to academic decline, was confirmed by the findings. Students with reported mental health issues had higher rates of academic decline (74.53%) compared to those without (61.61%). Likewise, the physical effects associated with excessive screen time — such as fatigue and tired eyes — were also linked to poorer academic performance. These health-related shocks are temporal shocks of the pandemic, meaning the pandemic suddenly affected everyone, then it prolonged, and disparities and inequalities arose between the subjects.

Notably, mental health analyses also revealed geographic divergence. Urban students were statistically more likely to report positive psychological well-being. Thus, mental health resilience associated with the pandemic could be contingent upon access to support systems, community infrastructure, or family dynamics—again evidencing the complex interaction of ecological levels across time.

Macrosystem: Structural and Cultural Contexts

The overall urban-rural divide observed for almost all variables in Hypothesis 7 suggests a macrosystemic structural inequality issue. The digital divide extends beyond individual-level disadvantages, reflecting systemic inequalities that are present across both urban and rural infrastructure. The persistent disadvantages attributed to rural students—digital device ownership, internet access, parental education, household income, and educational expenditure—imply that national cultural contexts and state policies favor urban populations over rural populations.

These findings together provide confirmatory evidence that Bronfenbrenner's Ecological Systems Theory serves as a practical framework for understanding the contextualized and interlinked experiences of students' digital access and academic performance in a global crisis. The theory enables an intersectional explanation that all levels of the system, combined and interactively, impact educational disparities. Thus, policy interventions must be equally layered – targeting infrastructural gaps, family-level support systems, and institutional readiness, to ensure that all students, irrespective of the geography they belong to, receive equitable opportunities to learn.

Authors' Contribution

MM conceived the overall concept of the paper, contributed to planning and preparing the methodology. NN was responsible for writing the manuscript, developing the theoretical framework, performing the statistical research, analyzing the results. TN helped write the paper, especially the literature reviews; AYS helped with the writing process, was responsible for executing the methodology.

CONCLUSION

This study aimed to investigate the effect of various ecological levels of Bronfenbrenner's Ecological Systems Theory on students' digital access and academic outcomes during the COVID-19 pandemic in Bangladesh. This mixed-method cross-sectional study aimed to determine student-level factors operating across the microsystem (digital access), ecosystem (socioeconomic status, parental education, occupation, and income), mesosystem (institutional support), chronosystem (health) and macrosystem (urban–rural structural inequalities) affecting participation in online learning and academic performance, using multinomial and logistic regression analyses. The results show that rural students, those from lower-income households, and students whose parents were less well-educated had significantly less access to devices and online learning. Academic deterioration was greater among students lacking their own digital device and those whose mental or physical health suffered in the pandemic. In contrast, students who benefited from subsidization were more likely to persist. Notably, a macrosystem pattern of structural educational inequality, characterized by urban–rural differences at nearly every level of the ecological model, was consistently observed to the disadvantage of rural students. These findings point to the need for future policies to centre on equitable digital inclusion — in the form of expanding affordable internet infrastructure and subsidizing digital devices for disadvantaged students. Institutional support—both financial and psychological—should become an integral part of school policies. In addition, targeted programming to address rural–urban divides through context-sensitive programming must consider the multi-layered ecological influences affecting student learning. The research operationalizes Bronfenbrenner's framework in a time of public health crisis to understand the reproduction of systemic inequalities in times of educational disruption thereby contributing to the field of educational research. Closing these gaps will require a holistic approach if we want to provide truly inclusive and resilient education systems that can withstand the shocks of future crises.

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