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ORIGINAL

Digital Divide in Science Education: The Role of Technology Access and Skills in Supporting Underserved Students

Brecha digital en la educación científica: el papel del acceso a la tecnología y las habilidades para apoyar a los estudiantes desfavorecidos

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ABSTRACT

Introduction: the Digital Divide (DD), refers to the gap among persons with varying levels of access to technology and digital skills, which significantly impacts educational outcomes.
Method: the research examines the impact of technology access and skills on underserved students, focusing on challenges they face in utilizing online learning and digital instruction through a cross-sectional survey of 479 university students. These factors were analyzed to identify how it supports or impede science learning. The descriptive and inferential statistics were used to evaluate responses. Variables, such as device ownership, Internet reliability, prior Online Learning (OL) experience, and technological skill levels were analyzed using regression and Analysis of Variance (ANOVA) models using International Business Machines Statistical Package for the Social Sciences (IBM SPSS) statistics version 17.0 to identify patterns and disparities.
Results: the findings revealed significant disparities in technology access and skills, with underserved students reporting lower device ownership and limited digital competence. With p-values of 0,0001 for device ownership, internet dependability, and technological proficiency, and a p-value of 0,004 for previous OL experience, the regression analysis demonstrated significant connections between all factors and OL engagement. ANOVA findings showed a p-value of 0,002 for the between-group variance, indicating significant differences between groups.
Conclusions: technological inequities in online science courses negatively impact underserved students, necessitating targeted institutional support and skill-building programs to improve learning outcomes and ensure equitable educational opportunities.

Keywords: DD; Science Education; Technological Access; Underserved Students; Educational Equity; OL.

RESUMEN

Introducción: la DD se refiere a la brecha entre personas con distintos niveles de acceso a la tecnología y las habilidades digitales, que afecta significativamente los resultados educativos.
Método: la investigación examina el impacto del acceso y las habilidades tecnológicas en los estudiantes desfavorecidos, centrándose en los desafíos que enfrentan en el uso del aprendizaje en línea y la instrucción digital a través de una encuesta transversal de 479 estudiantes universitarios. Estos factores se analizaron para identificar cómo apoyan o impiden el aprendizaje de las ciencias. Se utilizaron estadísticas descriptivas e inferenciales para evaluar las respuestas. Las variables, como la propiedad del dispositivo, la confiabilidad de Internet, la experiencia previa en OL y los niveles de habilidad tecnológica se analizaron utilizando modelos de regresión y ANOVA utilizando IBM SPSS Statistics versión 17.0 para identificar patrones y disparidades.
Resultados: los hallazgos revelaron disparidades significativas en el acceso y las habilidades tecnológicas, y los estudiantes desfavorecidos informaron una menor propiedad de dispositivos y una competencia digital limitada. Con valores p de 0,0001 para la propiedad de dispositivos, la confiabilidad de Internet y la competencia

tecnológica, y un valor p de 0,004 para la experiencia previa en OL, el análisis de regresión demostró conexiones significativas entre todos los factores y la participación en OL. Los hallazgos de ANOVA mostraron un valor p de 0,002 para la varianza entre grupos, lo que indica diferencias significativas entre los grupos.
Conclusiones: las desigualdades tecnológicas en los cursos de ciencias en línea afectan negativamente a los estudiantes desfavorecidos, lo que requiere apoyo institucional específico y programas de desarrollo de habilidades para mejorar los resultados de aprendizaje y garantizar oportunidades educativas equitativas.

Palabras clave: DD; Educación Científica; Acceso Tecnológico; Estudiantes Desfavorecidos; Equidad Educativa; OL.

INTRODUCTION

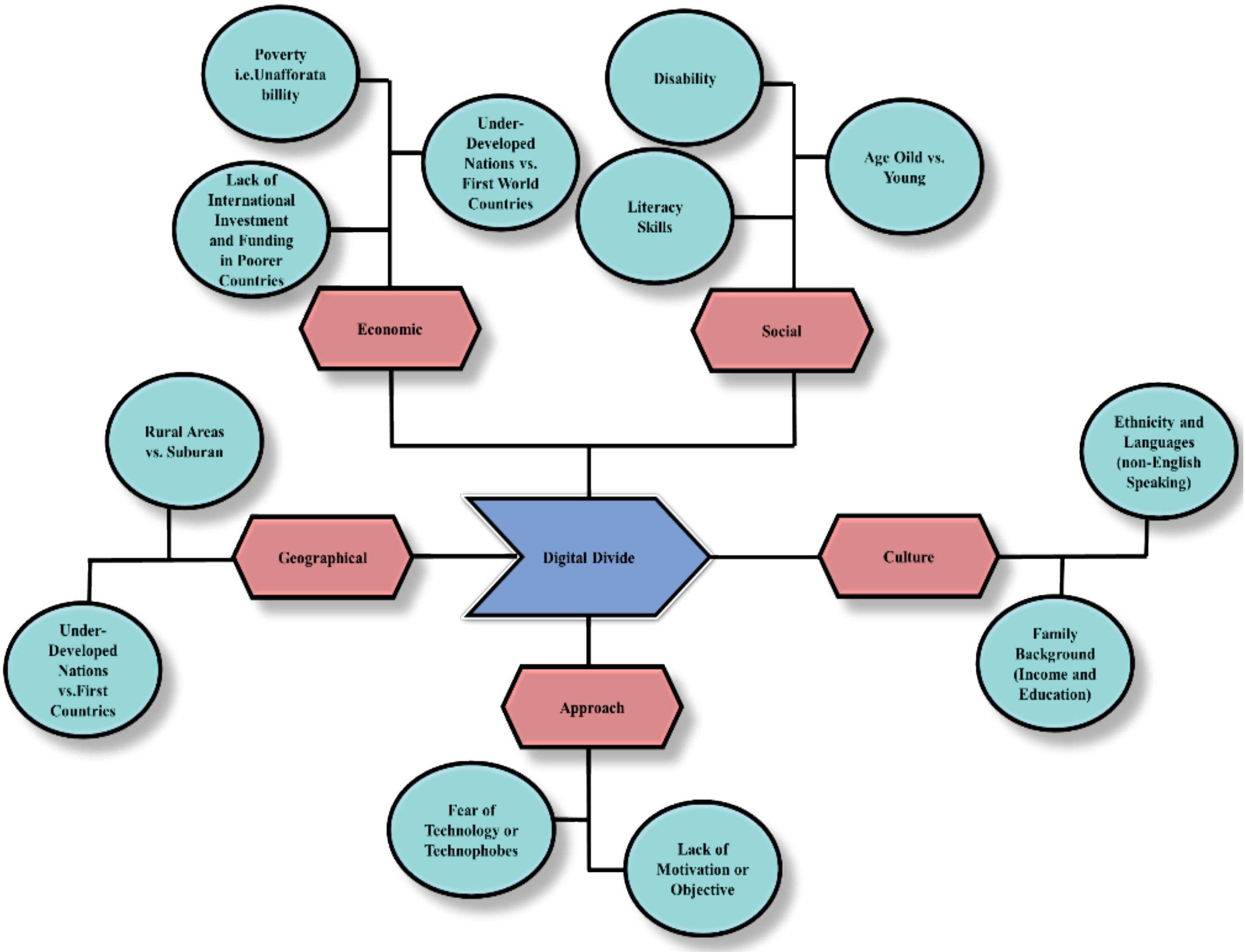

Figure 1. Key Determinants of the Digital Divide in Education

Technology has become a vital tool in learning during the twenty-first century, providing learners with an abundance of knowledge, making collaborative work easier, and enabling them to gain essential skills towards success in the future.(1) The DD, however, is used to describe the vast inequality in how various groups of learners can use and access technology in their learning processes.(2) This imbalance is especially evident in science education, where technology is instrumental in enabling experiments, simulations, and instant data analysis that enable students to grasp intricate, scientific ideas more effectively.(3) Technology access can be particularly difficult for underprivileged children, who can live in low-income families or in rural communities. These are obstacles such as the lack of training on how to use digital technology, poor internet connection, and a shortage of equipment.(4) Along with making it difficult for them to fully participate in contemporary scientific lessons, also adding to the increasing differences in achievement levels between them and their wealthier counterparts. Because these children are not provided with the opportunity to acquire the scientific and digital literacy competencies needed for both academic achievement and future jobs in Science, Technology, Engineering, and Mathematics (STEM) fields, the DD in science education thus generates equity problems.[5] The skills gap that prevails among students in disadvantaged communities worsens the problem. Certain students can have access to technology but frequently do not possess the skills required to utilize digital tools for learning.[6] Their ability to engage in interactive science lectures, conduct research, or use scientific software and tools, increasingly necessary to the modern classroom experience, can be greatly limited by a lack of proficiency.[7] To bridge these gaps, it is critical to comprehend the complex relationship between educational levels, digital competencies, and access to technology.[8] Focusing on the impact of these gaps on students' performance in school and future opportunities in STEM, the research investigates how digital literacy and access to technology can help poor children in science classrooms.[9] Science students must be capable of collaborating with others in virtual spaces, interpreting data, and conducting online research as well as having access to digital information. The ability to utilize technology effectively is increasingly becoming a key factor, particularly as science education gains more prominence in OL.[10] Through an exploration of the opportunity and challenge that the DD represents, the research hopes to shed some light on what can contribute to a more inclusive learning environment for all learners. Figure 1 shows how individuals with greater access to and technical know-how are able to best utilize Information and communication technologies (ICT).

The DD is a complex issue influenced by economic, social, geographical, cultural and approach factors, are illustrates in the above figure 1. In economic factor, Students who live in poverty or have fewer financial options have less access to technology and infrastructure, perpetuating the inequality that grows throughout the year. Social factors of students, such as age, disability, or literacy finance, have an effect on their levels of learning through science and technology. Geographic factors, such as rural areas that frequently lack internet access, and cultural factors, such as ethnicity, language barriers, and family background, all effect neglected academic possibilities to learners from non-English-speaking households or low-income families. Approach variables such as fear of technological devices, lack of desire, and independent understanding can all impede the adoption of technology, due to students with apprehension or ambiguous targets are less likely to interact with digital educational possibilities.

Key contributions

- The findings show that access to digital capabilities and technology is uneven among university students, particularly those from lower socioeconomic backgrounds. It also emphasizes how these variations impact online science course performance and attendance.
- Through a cross-sectional survey, the research collects empirical data from 479 university students, which can be generalized to provide an overview of the technological barriers and skill gaps across disciplines.
- Findings reveal significant disparities in technology access and skills, with underserved students reporting lower device ownership and limited digital competence. These gaps correlated with lower performance and participation in online science courses.

Research objective

The aim is to analyze the influence of access to and skills in technology on the academic achievements of disadvantaged students in university settings, with an emphasis on online science learning. The research explores disparities related to factors such as device ownership, internet connectivity, technological skills, and prior OL experience, which relate to student performance and participation.

Related works

The investigation looked at how approaches to learning, educational assets, parental participation, and academic routines influenced the mathematical ability of 53 STEM students from a secondary school in Southern Leyte.[11] Data were gathered utilizing standardized questionnaires and competence exams. According to the research, documenting abilities, mathematical proficiency, and internet access all showed a favorable influence on children' mathematics competency, however parental participation and time management had a substantial negative impact.

The research investigated the efficacy of DigiSTEM, a digital approach to STEM education that emphasizes teaching, learning, and assessment. It conducted mixed-methods[12] research that inquired into digital tools and platforms that improve student engagement and assessment accuracy. The findings revealed that digital technologies dramatically promote students' grasp and memory of complicated STEM subjects. However, concerns like as accessibility and teacher training need to be resolved. The report concluded with recommendations for educators, policymakers, and subsequent studies to better advance the integration of digital technology into STEM education.

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The usage of digital technology is becoming increasingly significant, particularly in the course of the COVID-19 epidemic. As a result, both men and women are needed skilled in the use of digital devices and networking technologies to teach and learn effectively. A research [13] endeavor was conducted at the University of Nairobi to determine the gender digital divide in the Faculty of Education. The results revealed a large gender gap, with only 6 and 8 men and no women graduating from the Masters of Science in Computer Science and Masters of Education Technology, respectively. The disparity is expected to have an impact on the number of women that consider positions related to information and communication technology.

Explored the usage frequencies of rural teachers, their perceptions of the effectiveness of technology, and barriers to adoption. The data were collected using a quantitative approach to their experiences with web-based technologies.[14] Results showed that there were different opinions about technology, with budgetary issues and student internet access as the primary barriers. Limitations include a lack of qualitative insights and limited diversity.

Examined the digital educational divide for susceptible students during the Coronavirus Disease 2019, focusing on access, connectivity, and the use of iPads. A survey of 518 students aged 10-15 was analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM).[15] Results show asynchronous learning and creativity skills were more significant than synchronous learning and productivity skills. Limitations include a specific age group and a focus on iPads.

Investigated ICT-related individual differences among secondary school students in Osun State, Nigeria, specifically: computer familiarity, Cognitive Behavioral Therapy (CBT) anxiety, and attitude, effects on UTME performance.[16] The research would suggest that access to equipment, particularly in disadvantaged areas, should be improved. Only the 2021 UTME candidates and geographical variances were addressed, which is a drawback of the investigation.

Investigated students during the Coronavirus Disease 2019, with a focus on ICT access. Both quantitative and qualitative data were collected using a cross-sectional survey.[17] The results emphasized that the high cost of data and inadequate network connectivity infrastructure make it impossible to participate in OL owing to research limitations on its generalizability. The cross-sectional survey contained both quantitative and qualitative data. Because of the research limitations on its generalizability, the findings showed that the high cost of data and the inadequate network connectivity infrastructure are obstacles to participation in OL.

Explored how Artifical Intelligence (AI) can assist bridge the DD by improving access to information, enhancing digital literacy, and promoting inclusion for underserved populations, such as the elderly.[18] The method of the research involves reviewing AI applications, theoretical concepts, and real-world examples. Results show that AI has the potential to address DD, though challenges remain in ethical concerns and accessibility.

Discussed the DD in healthcare through the patients' perspective, especially in terms of its cause, impacts, and possible solution.[19] Using 54 semi-structured interviews, the grades indicate the broader effects of the divide on employment, education, and social stability. Limitations include potential biases in the patient collection and focus on a single medical center's knowledge.

Examined how universities in Ghana managed the DD during the Coronavirus Disease 2019, online and blended learning.[20] Based on interviews with 35 faculty members, the research identifies some challenges, the utilization of digital technologies, and the provision of professional development, and provides insight into strategies and experiences for addressing these barriers and gaining a better understanding of the DD in sub-Saharan Africa.

Investigated Educational Programs for Health, Empowerment, and Access to Technology (EP-HEAT) workshops to improve digital inclusion and address social determinants of health in underserved EL Paso communities by providing technology education.[21] Methods included offering bilingual workshops and LinkedIn Learning Paths, followed by an anonymous mixed-method post-course survey. Results showed that 80 % of participants learned new skills, and 91 % completed the LinkedIn course. Limitations included potential biases in self-reported survey responses and the challenge of reaching all underserved groups.

Explored the effect of the Coronavirus Disease 2019, on learning technologies in United state (U.S). K-12 education, focusing on the DD and inter sectionalist. Data were collected from eight parents and nine teachers to understand challenges and best practices.[22] The results highlighted increased DD due to community support issues, while family discussions on racism and inter-sectionalism emerged. Limitations include the small sample size, restricting broader generalizability.

Investigated how the faculty coped with the very swift transition into remote learning in the spring semester of 2020, which focuses on issues of equity.[23] Faculty emphasized flexibility, its essential to know, and personalization from a care-based ethos in addressing concerns over equity. The results highlight the value of culturally sustainable online teaching strategies for reducing DD issues and promoting a fair learning environment.

Explored the DD in isolated education access for children during the 2019 coronavirus outbreak.[24] Inequalities in schooling during the pandemic were highlighted by data from a survey of 557 students and 626 parents,

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which showed that socioeconomic position, school type, and parental education level have a substantial impact on children's access to digital technologies.

Assessed the digital competencias of library and information science students. A student survey evaluated higher-level and technical digital skills for learning and daily activities.[25] Findings revealed gaps in digital creation, information literacy and identity management. Limitations include reliance on self-assessment and potential regional biases in digital competence perceptions.

Evaluated undergraduate students' perception of OL during the Coronavirus Disease 2019.[26] Using a survey of 358 students, the results showed that although students prefer physical classes, appreciate the changes in online delivery and their limits, which include the use of a survey from an Indian university and response bias.

Determined the perception by students of university-level digital capability and the impact of individual factors.[27] The quantitative approach involved a survey of 5164 students, and it showed positive perceptions about information literacy as well as communication. Additionally, significant differences were found in the areas of gender, grade level, and prior training. It reveals a need for targeted training in digital competence and self-reported data is one of the limitations of the research.

Research Gap

The frequency lies in the underrepresentation of convinced populations or regions, limited example sizes, and dependence on self-reported data, which can direct to biases. To address this issue in statistical methods, more varied and larger sample sizes should be used to enlarge generalizability. Employing robust statistical tools such as descriptive and inferential statistics, ANOVA, and IBM SPSS Statistics 17.0 can assist in offering a clearer analysis of the data, ensuring that associations among variables, such as DD and academic presentation, are captured exactly. The results can be improved by minimizing biases in the survey and using objective measurements.

METHOD

A sample size of 479 university students surveyed utilizing an assigned questionnaire to analyze the impact of access to technology and digital skills on science education in terms of device ownership, internet access, and digital tools for OL. Research used Likert-scale questions to assess and validate students' digital competence and willingness to engage in online science learning. It included factors like device possession, internet reliability, online learning experience, and self-perceived behavior technology skills. Participants rated the quality of their experiences and skill acquisition using scales ranging from "Strongly Disagree" to "Strongly Agree". Figure 2 illustrates the research flow structure and descriptive statistics were utilized to summarize the data, while regression and ANOVA models were applied to analyze associations among technological variables and science learning findings and highlight inequalities in terms of access and skills.

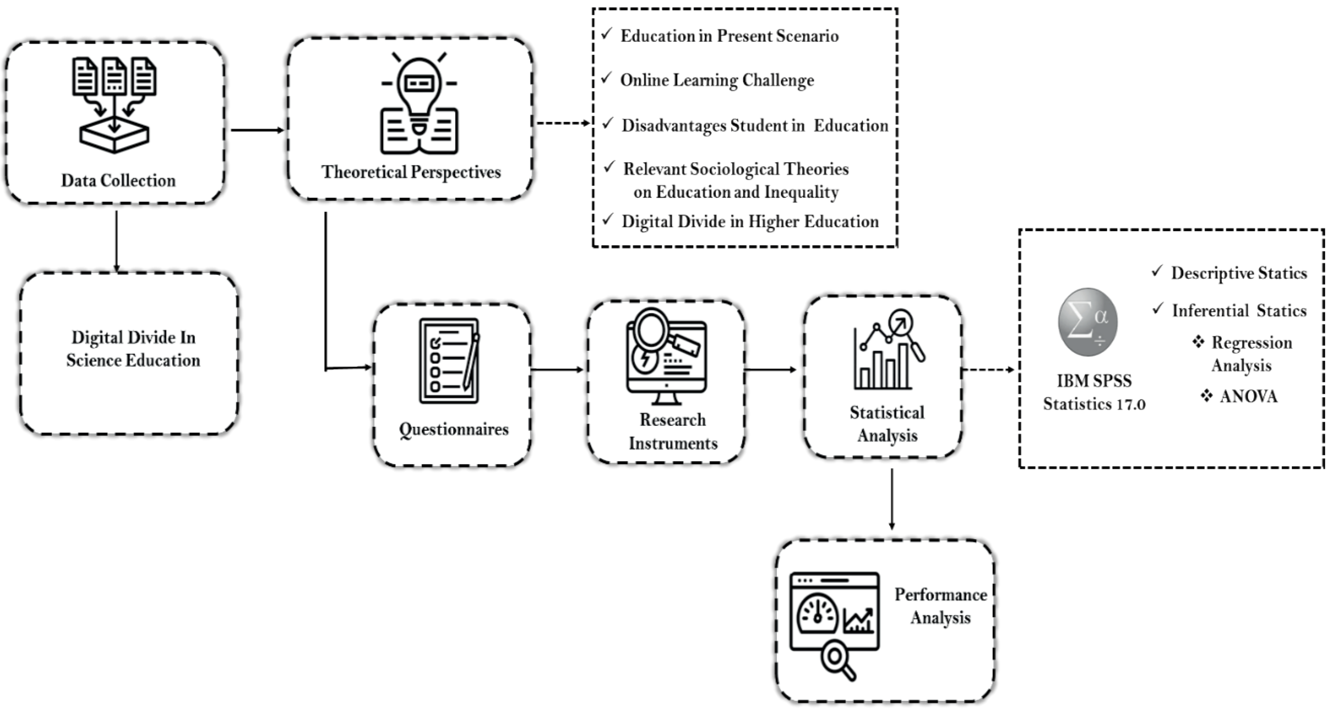

Figure 2. Framework for Streamlining Research Flow and Methodological Approaches

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These statistical analyses were able to highlight differences across conditions such as device ownership, reliability, extant online learning experiences, and technology-related skills, which provided a holistic view of how access to technology, digital skills, and online engagement shape educational experiences and outcomes.

Data collection

The dataset consists of a survey conducted by 479 university students from different departments, except first-term registrants. Variables include: possession of the device, Internet connection, previous experience with OL, and technological skills, which consist of general technological skills and specialized science learning. Data were collected to assess the effect of technology access and skills on participation and performance in online courses for science subjects.

Theoretical perspectives

The DD theory, which essentially tackles challenges of digital literacy and unequal access to technology as variables of educational achievement, is the foundation for several theories that were investigated. Effective learning is hindered by uneven access to digital tools and abilities, especially in OL contexts, the theory contends.

Education in the Present Scenario

Technology and internet platforms are used to deliver education more quickly. Both instructors and students found it to be a handy and helpful form of access throughout this unusual period. The biggest change in society has been brought by digitalization. The underprivileged group often struggles to access the internet due to various factors, such as inadequate network connections, remote outages, lack of high-quality devices, and lack of digital literacy. The New Education Policy 2020 emphasizes the importance of technology in delivering high-quality education, including creating digital libraries, encouraging language learning, and providing special attention to children with disabilities.[28] This underscores the urgent need to bridge the language barrier between teachers and students.

The digital divide in higher education

The modern world is more dynamic than ever because of the development of ICT everyone has access to or proficiency with the newest technology and DD has become a new kind of socioeconomic inequality.[29] The difficulties HEIs (Higher Education Institutions) encounter in satisfying the diverse needs of students with varied degrees of technology preparedness and inadequate technical abilities, which can impair the students' performance, are another indication that DD is also present in the higher education sector.

Online Learning Challenges

Higher education is widely recognized as a way of attaining economic success, the idea of the DD, which refers to uneven access to new technologies, has been a key focus of inquiry in the widespread usage of the Internet. Research indicates that learning that is aided by electronic technology can take several forms, including mixed or entirely online. A fully online course, often known as e-learning, is taught in a virtual classroom where students can be trained without physically in the same room as the instructor. This kind of education, commonly referred to as distant or remote learning, uses technology to offer students more flexibility about time and location by allowing learning synchronously or asynchronously at their own pace. Blended learning enhances student outcomes by creating more engaging and dynamic learning environments by fusing traditional classroom instruction with technology-mediated platforms.[30] Course design terminology like blended learning, hybrid or mixed modality, and flipping the classroom all relate to the same approach. Despite being hailed as a "revolutionary" solution to a variety of educational problems and inequalities, major challenges that emerged during the shutdown exposed the flaws of online education.

Disadvantaged students in Education

The participants gave the following examples of disadvantaged students: Disadvantaged Students are those who are unable to use distance learning platforms because of the lack of gadgets and/or Internet connectivity because of problems with their families, their social or economic situation, or their geographic location, which makes distant learning during the epidemic difficult.[31] The following instances of underprivileged students were provided by the participants:

- Low-income students who are unable to purchase a laptop or tablet.
- Students without access to the Internet or with inadequate connectivity reside in isolated places like deserts and rural areas.
- Living at an orphanage are orphans.

Each of these situations reflects broader systemic inequalities that make it difficult for students to access quality education through remote learning, highlighting the need for targeted interventions and support to bridge these gaps.

Relevant Sociological Theories on Education and Inequality

The pertinent sociological theories that deal with inequality and education must be taken into account to understand the sociological obstacles to fair digital learning. While social capital refers to the networks and connections that give people access to resources and assistance, cultural capital encompasses the abilities, information, and education that people have obtained. Theories of systemic inequality and social stratification also shed light on how these differences are maintained throughout time.[32] Knowing these ideas makes it easier to pinpoint the underlying reasons for inequality in online education and create solutions.

Questionnaire

The questionnaire is used to gather participants about how access to technology and digital skills affects science learning, especially among underrepresented university students, as are denoted in table 1. Participants assess their experiences concerning device ownership, internet connectivity, and using digital tools for OL. Additionally, it aims to assess the impact of participation and performance in online science courses. It also looks into ways in which previous OL experiences and their technology skill levels can assist or hinder students in engaging in digital-based education. More specifically, the research further explores how disparities in technology can affect a better outcome for learning in science education.

Table 1. Assessment of Questionnaire

S. No	Digital Divide and Technology Access in Science Education
1	How would you rate your overall access to digital devices (e.g., tablet, laptop, smartphone)?
2	How reliable is your Internet connectivity for online learning?
3	How often do you use digital tools (e.g., learning management systems, and research databases) for your studies?
4	Do you own a personal device (laptop, tablet, or smartphone) for online learning purposes?
5	How proficient are you in using digital tools for academic purposes (e.g., word processing, presentations, online research)?
6	Have you participated in any prior online learning courses or programs? If yes, how would you rate your experience?
7	How comfortable are you with accessing and using online resources for science courses?
8	How often do you face challenges in accessing online science learning materials due to technology issues (e.g., device malfunction, poor Internet)?
9	How confident are you in your ability to troubleshoot basic technical issues (e.g., software or device problems) during online learning?
10	To what extent do you feel that your technological access and skills impact your performance in science courses?
11	How would you rate the institutional support (e.g., technical help, device loans) available to you for online learning?
12	In your opinion, how important is it for universities to provide training programs to improve students' digital literacy?
13	How would you rate your level of preparedness for fully participating in online science courses based on your technological access and skills?
14	How do you think improving access to technology and digital skills could enhance your learning outcomes in science education?
15	What specific actions or programs would you suggest to bridge the technology access and skill gaps among underserved students in your university?

Research Instrument

To apply a set of Likert-scale questions to explore how available technology is to students' levels of digital competence, and their perceptions of what determines their willingness to engage in online science learning. The survey integrated items on possession of devices, internet reliability, experience in OL, and self-perceived skills in behavior technologies. Using rating scales ranging from "Strongly Disagree" to "Strongly Agree", participants assessed the quality of their experiences and skill acquisition. The focus was on evaluating the extent to which inequity in technology access and skills resulted in disparities in participation and achievement in science education for under-represented student populations. The outcomes highlighted gaps in access and digital skills ability, which were identified as critical bottlenecks of academic success.

Standard Deviation (SD)

Statistical Analysis

The statistics applied in analyzing the research embrace descriptive and inferential statistics to explain the relationship between two factors, namely, technological access and skills in the science learning outcome. For the statistical analysis, both descriptive and inferential statistics were used to analyze the results, based on IBM SPSS Statistics version 17.0. The models applied to some of the variables included multiple regression and ANOVA. Technology proficiency, prior experience with OL, internet dependability, and device ownership were the variables that were analyzed. These findings demonstrate that to guarantee improved educational outcomes for these pupils, technological disparities must be addressed.

- Descriptive Statistics: descriptive statistical approaches were used to compile and report the survey data's fundamental characteristics, including device ownership, internet dependability, prior OL experience, technical access, and skill level. As needed to characterize the participant's responses, which are subsequently examined in terms of distributions, central tendencies, and variances, these provide a general picture of their technical access and skill level. The mean, median, and SD were probably utilized to measure the variables.
- Inferential Statistics: inferential statistical techniques such as regression analysis and ANOVA were employed. The results dependent on several characteristics, such as owning a gadget or having technological abilities, could be investigated using regression models. The means for different student groups, depending on the variations in their access to technology could be compared using ANOVA. Particularly between underprivileged and other pupils, these techniques assisted in identifying notable differences in digital proficiency and access.
- Regression Analysis: inferential methods of statistics consist of regression analysis and ANOVA. The regression models were valuable to apply in investigating the result based on a variety of factors such as owning a device or possessing skill. ANOVA was used to assess the means of different groups of students based on the difference in their information access. These methods assist in recognizing important disparities in knowledge access and capability, especially among underserved and other students.
- ANOVA: ANOVA is the statistical method practical in the research to establish there are a variety of groups to find where the differences in technical access and skills exist among different subgroups of students. It shows if there are actual differences where device ownership, internet reliability, and even the level of technological skills is involved in the real difference in the participation and performance of students taking online science courses, thereby providing attentiveness to disparities that affect the underserved students.

RESULTS

The results exhibited considerable differences in access to technology, and in skills for learning, indicating students who are disadvantaged experience barriers to taking science courses online. The significant p-values from the ANOVA and the regression analysis provided additional evidence about the importance of addressing the equity gap to help improve educational outcomes and create equitable learning opportunities in science for all students. Device ownership, availability of the internet, online experiences before attending college, and technical expertise are factors that prevent one from participating fully online and performing better in science. Reports from underrepresented groups indicate fewer device owner and lower digital capability, which negatively impact their experience in science education. The results indicate that to close these technology disparities and guarantee that every student has equitable access to education, attentive institutional assistance and skill-building initiatives are required.

Participants of the Demographic

The demographic characteristics table 2 summarizes the distribution of 479 university students across various categories. The sample consists of 48 % male and 50 % female participants, with a small percentage (2 %) recognizing as non-binary or other. Most participants are aged 18-22 (60 %), while 30 % are between 23-30 years old, and 10 % are aged 31 and above. In terms of academic discipline, 40 % are studying science-related fields, 30 % are in engineering, and 30 % are from humanities or social sciences. A significant majority (70 %) has high-speed internet access, and most participants own a smartphone (85 %) or a laptop/PC (75 %). Regarding prior experience, 65 % have engaged in OL, and 30 % report high technological skill levels, with 50 % rating their skills as moderate and 20 % as low. Figure 3 demonstrate the graphical representation of device ownership and technological skill level.

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Table 2. Overview of Demographic and Technological Profiles (N = 479)	
Demographic Characteristics	**N = 479 (%)**
Gender	
Male	230 (48)
Female	239 (50)
Non-binary/Other	10 (2)
Age Group	
18-22	287 (60)
23-30	144 (30)
31+	48 (10)
Discipline of Study	
Science (e.g., Biology, Chemistry)	192 (40)
Engineering	144 (30)
Humanities	72 (15)
Social Sciences	72 (15)
Internet Access	
High-speed broadband	335 (70)
Limited or intermittent access	120 (25)
No access	24 (5)
Device Ownership	
Smartphone	407 (85)
Laptop/PC	39 (8)
Tablet	23(5)
None	10 (2)
Prior Online Learning Experience	
Yes	311 (65)
No	168 (35)
Technological Skill Level	
High	144 (30)
Moderate	239 (50)
Low	96 (20)

Descriptive Statistics

The descriptive statistics primarily summarize technological access and skills among university students, with a specific focus on the underserved population. The results obtained indicated considerable gaps in technology access, as underserved students indicated fewer device ownership and internet connections. It also demonstrated a low level of digital competence, which affected their engagement with OL environments. The survey exposed the variation in prior OL experiences, further influencing their participation and performance in online science courses. The research examined the distribution of variables, such as ownership, internet access, and technology skills to better understand how these influence inequities in online education and more targeted interventions can be needed. Table 3 demonstrates the statistical summary of technological factors in OL. The mean and SD results' descriptive statistics are shown in figure 3.

Table 3. Descriptive Statistics of Technology-Related Variables				
Variables	**Mean**	**SD**	**Minimum**	**Maximum**
Device Ownership	2,4	0,8	1	4
Internet Reliability	3,2	1,1	1	5
Prior OL Experience	3,0	1,2	1	5
Technological Skill Levels	2,5	0,9	1	5

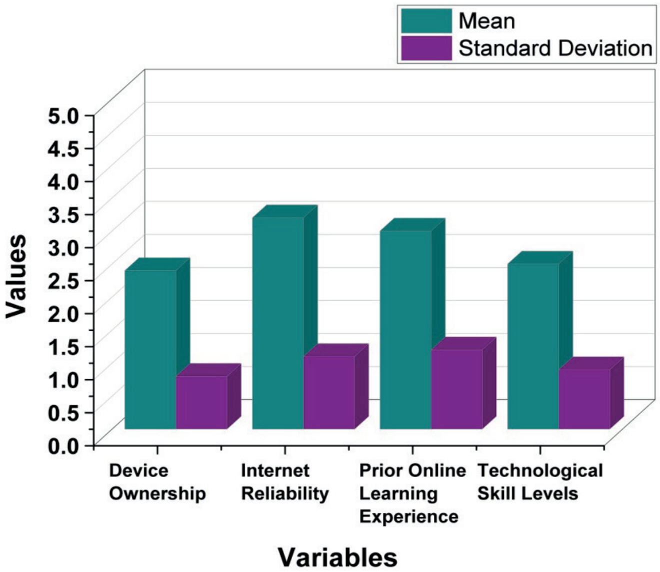

Figure 3. Visualization of Central Tendency and Dispersion with Mean and SD

Inferential Statistics

Inferential statistics, including regression analysis and ANOVA, are employed to test hypotheses and draw conclusions regarding variables. While ANOVA compared means for different student groups based on differences in technology availability, regression models examined the findings based on variables like device ownership and technological proficiency. These methods revealed notable disparities in access to and competency with technology, particularly between disadvantaged and other students.

Regression analysis

Regression analysis is important in the research of the DD of science education because it shows how students' performance and participation in online science courses are related to key factors like device ownership, internet reliability, prior OL experience, and technological skill levels. The regression model calculates how differences in technological proficiency and access affect academic results. The results show that low performance in scientific education can be strongly predicted by pupils from low socioeconomic backgrounds who have lower device ownership and inadequate digital capabilities.

Regression analysis can shed light on how technology inequality contributes to DDs and emphasize the need to focus interventions on student access and skill development. Table 4 illustrates coefficients from the regression model predicting OL engagement. The SE (Standard Error) and coefficient indications from regression analysis are shown in figure 4.

Table 4. Regression Analysis of Factors Influencing Online Learning Engagement

Variables	(β)	SE	t-value	p-value
Device Ownership	0,25	0,05	5,00	0,0001
Internet Reliability	0,30	0,06	5,00	0,0001
Prior OL Experience	0,20	0,07	2,86	0,004
Technological Skill Levels	0,35	0,05	7,00	0,0001
Intercept	0,10	0,08	1,25	0,21

The regression analysis outcomes exploring the relationships between various factors and the dependent variable are shown in the table 4. Evidence suggests that Device Ownership (β = 0,25) increases the dependent variable by 25 % for each additional unit of device ownership and this was found statistically significant (p-value 0,0001). In an Internet Reliability (β = 0,30) exhibit an increase of 30 % in dependent variable for each unit increase in internet reliability and was statistically significant (p-value 0,0001). The Prior OL Experience (β = 0,20) findings indicated a 20 % increase in the dependent variable for each unit increase in prior online learning experience and this was deemed statistically significant (p-value 0,004). Technological Skill Levels (β = 0,35) showed a strong impact indicating that for each unit increase in technological skill levels, the dependent variable increased by 35 %. A high t-value (7,00) found this statistically significant (p-value 0,0001). Finally, the

Intercept (β = 0,10) indicates that when all other variables are zero the dependent variable is expected to be 0,10 but had p-value. 0,21, which is not statistically significant.

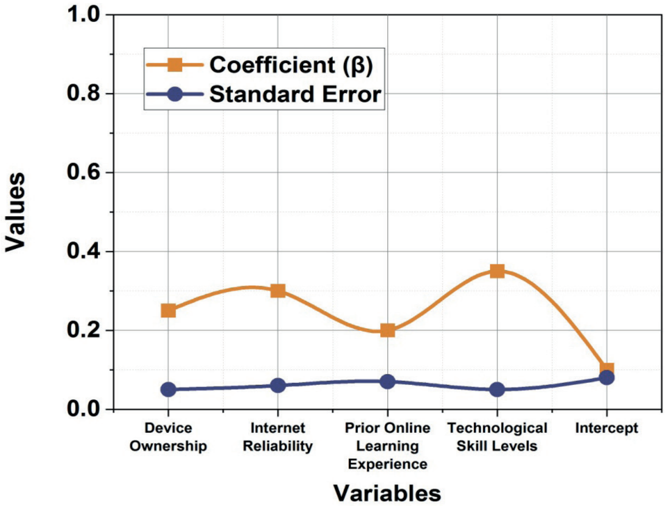

Figure 4. Depiction of Coefficient Values and Standard Errors in Regression Analysis

Analysis of Variance (ANOVA)

Using ANOVA, the research covered variables such as device ownership, Internet connectivity, and technological skill levels, where significant gaps emerged between the underserved and their peers. Results showed that limited availability of devices and digital tools, as well as a lower level of technological skills, significantly affected the students' performance and participation in the online science course. These findings warrant are targeted interventions aimed at bridging the DD and equity gaps in learning opportunities during science education. Group differences are statistically significant, illustrated in table 5.

Table 5. ANOVA table for Statistical Consequence of Group Differences

Source of Variation	SS[1]	MS[2]	Df[3]	F-Value	p-value
Between Groups	120,45	40,15	3	5,35	0,002
Within Groups	375,85	0,79	475	-	-
Total	496,30	-	478	-	-

Note: [1]Sum of Square, [2]Mean Square, [3]Degrees of Freedom

Outcomes of measures scale

The Likert scale survey measures various factors related to the DD in Science Education. Each factor device ownership, internet reliability, prior OL experience, and technological skill level addresses key elements that can influence access to and engagement with online science education. Device ownership reflects the availability of technology for students, where a significant portion disagrees or strongly disagrees, indicating a potential barrier. Internet reliability highlights challenges in accessing stable online resources, with varied opinions on connectivity. Prior OL Experience measures students' previous exposure to digital learning environments, showing a relatively higher positive response, suggesting familiarity with online education. Technological skill levels assess the proficiency of students in using digital tools, revealing mixed responses that imply a gap in skill development. Figure 5 and table 6 display the Likert scale responses.

Table 6. Measuring Intensity of Agreement/Disagreement

Factor	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Device Ownership	25 %	20 %	15 %	30 %	10 %
Internet Reliability	15 %	25 %	20 %	30 %	10 %
Prior OL Experience	10 %	15 %	20 %	30 %	25 %
Technological Skill Levels	20 %	30 %	15 %	25 %	10 %

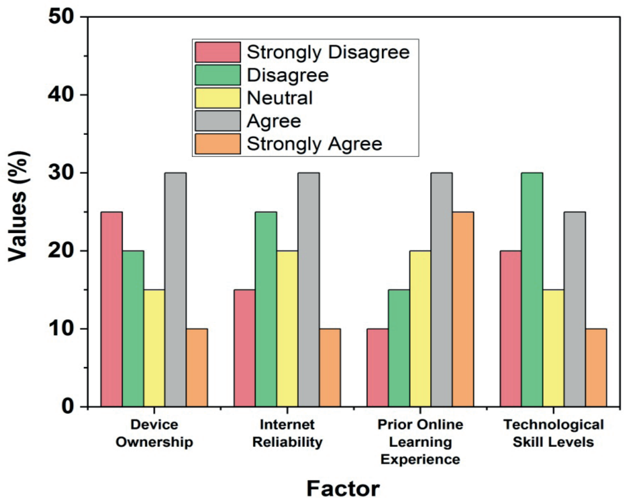

Figure 5. Graphical Overview of Likert Scale Data and Response Frequencies

DISCUSSION

Disparities in device ownership and digital competency act as obstacles to these students' full participation in OL and hinder their academic performance, as evidenced by the significant impact that technology availability and proficiency have on educational outcomes, especially when it comes to scientific instruction for disadvantaged students. Such inequities further widen gaps in education, rendering it challenging for students from disadvantaged backgrounds to compete well in these digital learning environments.

The research [11] emphasized on STEM students can restrict its broader applicability. The subsequent research should include varied academic backgrounds and longitudinal studies for improved comprehension of the factors that influence mathematical ability across fields. Qualitative research approaches like as interviews or focus groups provide more in-depth insights into students' experiences and perceptions on the aspects that influence their mathematical ability. The research lacks longitudinal data, focuses on STEM fields, and is not applicable globally. It also lacks equal technology[12] access and student feedback to understand the long-term effects of digital tools on student outcomes. The gender divide as it relates to ICT education as well as digital literacy in education[13] in Kenya. Nevertheless, it does not give an explicit description on impacts of digital literacy at the different educational levels, it does not include marginalized peoples, and does not include its exploration for sustainability nor geographic inequalities in access to digital technologies. The absence of qualitative data limits the depth of understanding of teachers'[14] experiences with technology, while the lack of sample diversity in population means the findings cannot be generalized to other populations. Specifically, focusing on a specific age group (students aged 10-15) and iPads limits the [15] study can be generalized to other populations of students with age and devices. Similarly, the research [16] focus on 2021 UTME candidates in Osun State, Nigeria, biases the findings to a more narrow age and geographic location for the applicability of the findings to other students in Nigeria or outside Nigeria. The research [17] used a cross-sectional survey method and limits generalizability suggest broader conclusions cannot be made about student access to ICT during the pandemic— this is specific to the data costs in the region and data infrastructure. Further, in terms of applying AI it limits implications, because while it is clear that AI can assist in bridging the DD,[18] the research lacks data to substantiate the claim and mainly relies on theory and real-world examples to help understand the data.

Possible biases with semi-structured interviewees[19] and the results from a typical single medical clinic limits the generalizability of the data related to the digital divide experienced in healthcare. Additionally, the small number of participants (35 faculty members) fuels limited[20] generalizability related to how universities in Ghana were managing the DD during the pandemic, and this is especially true in a sub-Saharan African context. When considering survey data, there are possible biases due to self-reporting, and limitations caused by being unable to contact all[21] groups underserved by their local community, when evaluating possible effects of technology education workshops offered to underserved El Paso demographics. The relatively low sample of parents (n=8) and teachers (n=9) minimized the generalizability of the data findings[22] related to the digital divide in relation to U.S. K-12 education, again meaning these findings cannot be easily applied to a broader context.[23,24,25,26] Lastly, the data generated from faculty experiences during the emergency transition to remote instruction in 2020, was specific to an event in time, and did not include[27] consideration of long-term initiatives addressing the digital divide in higher education. Lastly, the survey data from 557 students and 626 parents limited interpretations based on socioeconomic[28] and education variables and may not be applied to higher level disparities in digital access across the wider population.[29,30,31,32] The dependency on self-assessment in the assessment of library and information science students' digital capabilities[33] created potential bias and restricts the validity of perceived technol gical capabilities.[34,35,36,37] The potential regional bias and response bias of utilizing survey data from an Indian university[28] influenced the applicability of the data on undergraduate students' perceptions of online learning during the lockdown phase of the pandemic.[39,40,41,42] The use of a self-reported and lack of control over[43] extraneous variables in the assessment of university students' digital capabilities in varying contexts limits the trustworthiness of the findings related to digital competence and training for improvement opportunities.[44,45,46,47,48]

There appears to be a link between poorer performance and less access to technology, which calls for quick action. The implementation of institutional support, such as skill-building programs, improved internet connectivity, and equal access to equipment, would be fundamental interventions to eliminate such disparities. Institutions should subsidize device loans, partner with ISPs for low-cost internet, and integrate digital literacy modules into curricula. "By addressing these technological gaps, educational institutions can become more accessible and egalitarian while also improving the educational experience for disadvantaged students.

CONCLUSIONS

Digital literacy and utilization of technology have an impact on how students learn in scientific education. The limitations that apply to these students when using OL resources are demonstrated by minor variations in computer ownership, Internet access, and technological proficiency. The results of the research show significant inequities in indicators pertaining to student access and abilities with technology and the separate issues impact student engagement and performance in online science courses for at-risk students. Descriptive statistics show inequities in device ownership (Mean = 2,4, SD = 0,8), internet reliability (Mean = 3,2, SD = 1,1), and overall levels of technology skill (Mean = 2,5, SD = 0,9). A regression analysis showed that device ownership (β = 0,25), internet reliability (β = 0,30), and skill with technology (β = 0,35) impacted online learning engagement, with statistically significant p-values for each ($p < 0,05$). ANOVA results (F-value = 5,35, p = 0,002) indicated there were significant differences between groups across each of these variables, underscoring a need for more in-depth research to better understand these digital inequities. Likert scale responses also supported these findings as a barrier to online science engagement surfaces with those who agreed or strongly disagreed on device ownership (25 %) and internet reliability (15 %). The research highlights the need for targeted initiatives, like improved access to technology and skill-building programs, to bridge these gaps. With p-values of 0,0001 for technological skill, internet dependability, and device ownership, and a p-value of 0,004 for previous OL experience, the regression analysis demonstrated significant connections between all characteristics and OL involvement. Educational institutions can enhance the academic performance and involvement of underprivileged students in science classes by creating more equal learning environments. Overall, these findings demonstrate the need to development students' access to technology to promote equity in educational opportunities

Limitations and Future Research

The main drawback is its cross-sectional design, which only provides students with a peek, with a glimpse of occurring during a specific period. The fact that the research only includes those who are not enrolled in the first term and leaves such people might have an impact. Future studies would aim to comprehend changes over longer periods, longitudinally, and the efficacy of specific treatments aimed at digital tool access and proficiency. Additionally, research could examine the socioeconomic elements that might make DD either worse or less severe in various educational settings.

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