Impact of Virtual Learning on Student Performance and Engagement in Remote Hilly Areas of Uttarakhand

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KEYWORDS
Virtual Learning, Student Performance, Student Engagement, Remote Hilly Areas, Educational Technology.

ABSTRACT:
The rapid shift to virtual learning during the COVID-19 pandemic brought significant changes to the education system, especially in geographically challenging regions like the remote hilly areas of Uttarakhand, India. This study explores how these shifts affected high school students' academic performance and engagement in virtual classrooms, given the unique challenges posed by limited infrastructure and connectivity. This study investigates the impact of virtual learning on student performance and engagement in the remote hilly areas of Uttarakhand, India. With the sudden shift to virtual education during the COVID-19 pandemic, schools in these regions faced unique challenges due to their geographic isolation, lack of internet access, and frequent power outages. The study aims to assess how these conditions have influenced the effectiveness of virtual learning and its impact on students' academic outcomes and engagement levels. A total of 51 high school students from 05 government schools in remote areas of Uttarakhand participated in this research. Data was collected through structured questionnaires, focusing on students' experiences with virtual learning, their academic performance before and after the shift, and their engagement with online classes. The study used both quantitative and qualitative methods, including descriptive statistics, logistic regression, and MANOVA, to analyze the data. Findings indicate that while virtual learning provided an essential educational lifeline during the pandemic, students in remote areas encountered significant barriers that hindered their learning experiences. Limited internet access and frequent electricity cuts were among the primary obstacles reported. Despite these challenges, a majority of students found virtual classrooms useful for maintaining continuity in their education. The study also reveals that virtual learning positively influenced student engagement, particularly in subjects that incorporated interactive content. However, the overall academic performance showed mixed results, with some students struggling due to the absence of traditional classroom interaction and practical learning opportunities. This research highlights the need for improved infrastructure and policy interventions to support virtual education in remote regions. It concludes that while virtual learning has potential, addressing technological and logistical barriers is crucial for ensuring equitable and effective learning experiences for all students in such areas.

1. Introduction

In recent years, the advancement of technology has significantly influenced the education sector. One of the most transformative changes has been the emergence of virtual learning, particularly after the onset of the COVID-19 pandemic. Virtual learning, characterized by the use of digital platforms to deliver educational content, has become a critical tool for maintaining educational continuity when in-person classes are not feasible. Its importance was further highlighted during the pandemic when millions of students globally were forced to transition to online education due to school closures. This shift has sparked widespread interest in understanding the role and effectiveness of virtual learning, especially in regions where access to traditional education is limited[1], [2].

The advent of virtual learning has provided a unique solution to many educational challenges by offering flexibility, accessibility, and the ability to customize learning experiences to suit individual student needs. Virtual learning platforms enable students to access educational materials from anywhere at any time, making it particularly useful in maintaining educational continuity during crises. This form of learning has proven beneficial in many ways, such as providing access to resources not available locally and promoting self-directed learning.

However, the real importance of virtual learning emerged in response to the COVID-19 pandemic, when physical classrooms became inaccessible for an extended period. Schools worldwide had to pivot quickly to online teaching, forcing educators and students to adapt to virtual learning methods. In many urban and developed regions, this transition was relatively smooth due to the availability of infrastructure such as high-speed internet, digital devices, and well-trained teachers. However, in remote regions, especially in developing countries, the sudden shift to virtual learning brought to the forefront several underlying challenges[3]–[5].

One such region that faced significant challenges in this shift is the remote hilly areas of Uttarakhand, India (Uttarkashi, Paudi Garhwal, Bageshwar, Rudraprayag, Tehri Garhwal). Education in these areas has long been a struggle due to geographical isolation, inadequate infrastructure, and economic constraints. Schools in these regions often lack the basic facilities that are readily available in urban areas, such as well-equipped classrooms, libraries, and trained teaching staff. For students in these areas, attending school involves overcoming numerous obstacles, including long commutes across difficult terrains and unpredictable weather conditions. Despite these challenges, the importance of education in these regions cannot be overstated, as it plays a crucial role in breaking the cycle of poverty and promoting socio-economic development[6].

The COVID-19 pandemic exacerbated the existing challenges in the education sector of Uttarakhand's hilly regions, necessitating the urgent adoption of virtual learning platforms. While virtual learning presented a potential solution, it also highlighted new challenges specific to these regions. The pandemic underscored the importance of finding alternative teaching methods to ensure that students in remote areas could continue their education. However, the effectiveness of virtual learning in these regions remains largely unexplored, raising important questions about its impact on student performance and engagement[7], [8].

Despite the potential benefits of virtual learning, students in the remote hilly areas of Uttarakhand face numerous challenges that hinder their ability to fully participate in online education. Internet accessibility is one of the primary challenges in these regions. Limited or no access to high-speed internet prevents students from participating in live classes or accessing learning resources online. Electricity issues also pose a significant problem, as power cuts are frequent in these areas, disrupting students' ability to engage consistently in virtual learning.

Moreover, the lack of infrastructure, such as digital devices like smartphones, tablets, or laptops, further limits students' participation in virtual classes. In many cases, families may not have the financial means to provide their children with the necessary tools for online education. Also, the absence of proper training for both students and teachers in navigating online learning platforms adds to the challenges, resulting in reduced engagement and performance[9].

Another key issue is the lack of research on the effectiveness of virtual learning in such geographically and economically disadvantaged regions. While studies have been conducted on the general effectiveness of virtual learning, there is a gap in the research concerning its impact on students in remote hilly areas like those in Uttarakhand. Understanding how virtual learning affects student performance and engagement in these areas is crucial for developing effective strategies to support students and improve the quality of education.

The primary objective of this research is to assess the impact of virtual learning on student performance and engagement in the remote hilly areas of Uttarakhand. Specifically, this study aims to:

1. Evaluate how virtual learning has affected the academic performance of high school students in these regions.

2. Examine the level of student engagement in virtual learning environments compared to traditional classroom settings.

3. Identify the major challenges students face in accessing and adopting virtual learning, with a focus on technological, infrastructural, and socio-economic barriers.

4. Explore the perception of both students and teachers towards virtual learning in these areas.

5. Offer recommendations for improving the virtual learning experience for students in remote hilly regions.

This study seeks to answer the following key research questions:

1. How has virtual learning affected the academic performance and engagement of students in the remote hilly areas of Uttarakhand?

2. What are the major challenges faced by students in adopting virtual learning in these regions, particularly regarding internet accessibility, electricity, and infrastructure?

3. How do students and teachers perceive the effectiveness and value of virtual learning in these areas, compared to traditional in-person education?

By addressing these questions, this research will provide valuable insights into the current state of virtual learning in Uttarakhand's hilly regions and contribute to the broader understanding of how digital education can be made more effective and inclusive for students in geographically isolated and underserved areas. Additionally, the findings from this research will offer policy recommendations to improve the implementation of virtual learning programs and support the educational development of students in remote regions.

2. Literature Review

The evolution of e-learning has seen a significant transformation, particularly in developing countries where digital infrastructure has gradually improved. The transition from traditional learning environments to virtual learning has been driven by the need for accessible and flexible education. E-learning platforms provide students with opportunities to learn at their own pace, access a broader range of educational materials, and engage in interactive learning environments. In many developing countries, the integration of technology in education has helped bridge the gap between urban and rural students, allowing learners in remote areas to access quality education that was previously unavailable to them[10]. This shift has been further accelerated by the increasing use of mobile technology, which offers students an alternative to traditional classroom-based learning[11].

Globally, virtual learning technologies have included platforms such as Moodle, Google Classroom, and Microsoft Teams, all of which offer online resources and interactive features for both students and teachers. In India, the adoption of virtual learning technologies has been a response to the growing demand for educational accessibility, particularly in areas where physical schooling is either limited or unavailable. The Indian government has also introduced initiatives like SWAYAM, which provides online learning resources across a range of subjects, further promoting e-learning in both urban and rural areas[12].

Virtual Learning in Remote Areas

In rural and remote areas, the implementation of virtual learning faces numerous challenges, particularly related to infrastructure and technology. Several studies have highlighted the digital divide between urban and rural students, where access to reliable internet, electricity, and digital devices is a major issue[13]. In regions with limited connectivity, students often struggle to participate in virtual classrooms, leading to significant disparities in educational outcomes. Additionally, the lack of technical support and the inadequate training of both students and teachers in using online platforms exacerbate these challenges[14].

Technological barriers such as poor internet bandwidth and frequent electricity cuts are particularly prevalent in rural areas, including the hilly regions of Uttarakhand. These barriers not only limit students' ability to access online lessons but also disrupt their engagement with learning materials, causing further difficulties in maintaining educational continuity. The infrastructural challenges in these regions also include the lack of digital devices, with many families unable to afford the technology required for online learning. This has been a significant issue in areas where schools have had to switch to virtual learning due to the pandemic, leaving many students without the necessary tools to continue their education[15].

The digital divide in rural areas is a critical factor that has influenced the adoption of virtual learning. In many cases, students in these regions have had to rely on sporadic access to technology, often sharing devices with family members or using community resources. This has led to a fragmented learning experience, with students unable to fully engage with their education in the same way as their urban counterparts[16]. Furthermore, the lack of stable internet connections and consistent power supply has limited the effectiveness of virtual learning, making it challenging for students to participate in live sessions or access online resources[17].

Impact on Student Performance and Engagement

Several studies have explored the relationship between virtual learning and academic performance. While virtual learning offers flexibility and accessibility, its impact on student performance is often mixed. In some cases, students who are self-motivated and disciplined have thrived in online learning environments, benefiting

from the ability to study at their own pace and access a wider range of resources. However, other students, particularly those who require more structure and guidance, have struggled to stay engaged and maintain academic performance in virtual settings[18].

Student engagement in virtual learning environments has been a topic of much debate. On the one hand, virtual learning can increase engagement by offering interactive tools, such as quizzes, videos, and discussion forums, which enhance the learning experience. On the other hand, the lack of face-to-face interaction and the absence of a traditional classroom environment can lead to disengagement, particularly for students who struggle with self-regulation and time management[19]. In regions like Uttarakhand, where students face additional barriers such as limited internet access and power outages, maintaining engagement in virtual learning has been especially challenging. These issues have led to concerns about the long-term impact of virtual learning on student performance, particularly in terms of retention and knowledge acquisition[20].

The effectiveness of virtual learning in terms of academic performance is also influenced by the subject matter. Practical subjects, such as science and mathematics, often require hands-on activities and experiments, which are difficult to replicate in a virtual environment. As a result, students in these subjects may experience lower levels of engagement and understanding compared to those in more theory-based subjects, such as history or literature. This disparity in engagement across different subjects has been a key factor in understanding the limitations of virtual learning, particularly in remote areas where resources for practical learning are limited[21].

Context of Uttarakhand

Uttarakhand's hilly regions present unique geographical challenges that further complicate the implementation of virtual learning. The mountainous terrain and scattered populations make it difficult to establish the infrastructure necessary for reliable internet access and electricity supply. These geographical challenges have long hindered the delivery of education in the region, and the shift to virtual learning has only highlighted these issues further[22].

Despite these challenges, the Indian government has made efforts to promote virtual learning in remote areas, including Uttarakhand. Various educational policies and initiatives have been introduced to bridge the gap between urban and rural students, with a focus on improving digital literacy and providing access to online learning platforms. Programs such as SWAYAM and DIKSHA aim to provide quality educational resources to students in remote areas, offering them the opportunity to continue their education despite the geographical and infrastructural challenges they face. However, while these initiatives have made some progress, the lack of reliable infrastructure remains a significant barrier to the widespread adoption of virtual learning in Uttarakhand's hilly regions.

3. Methodology

This section outlines the processes and techniques that will be used to conduct this research on the impact of virtual learning on student performance and engagement in the remote hilly areas of Uttarakhand. Given the unique challenges faced by students in these regions, this section will combine both quantitative and qualitative approaches to provide a comprehensive understanding of the issue. The goal is to gather detailed and reliable data that can be analyzed to identify patterns, trends, and challenges related to virtual learning.

3.1. Research Design

The research employs a mixed-methods approach, incorporating both quantitative and qualitative methods. This approach is suitable because it allows for a more comprehensive understanding of the problem by capturing both numerical data (through quantitative methods) and descriptive insights (through qualitative methods).

3.1.1. Quantitative Approach

- The quantitative component involves the collection and analysis of numerical data from the sample population. This data is gathered through structured questionnaires, designed to collect information on various aspects of virtual learning, including hours spent in virtual classes, academic performance, engagement levels, and the availability of resources like internet and digital devices.

- This approach is critical in identifying patterns and trends across a larger group of students. Descriptive statistics will be used to summarize the data, such as calculating the mean, median, and mode for responses related to academic performance, internet access, and hours spent learning. Inferential analysis will also be conducted to make predictions or generalizations about the wider student population in Uttarakhand's remote areas. Statistical techniques such as logistic regression and MANOVA (Multivariate Analysis of Variance) will be used to assess relationships between variables such as the availability of resources and student performance.

3.1.2. Qualitative Approach

- The qualitative component complements the quantitative data by capturing the personal experiences and perceptions of students regarding virtual learning. Open-ended questions in the questionnaire allow students to express their challenges and insights into how virtual learning has impacted their engagement and performance.

- Qualitative analysis will be used to identify common themes, such as the difficulties faced in accessing online classes due to poor internet connectivity or electricity issues, as well as the psychological effects of learning in isolation without direct teacher interaction. The qualitative approach will help provide a richer understanding of the context in which the quantitative results exist.

3.2. Descriptive Statistics and Inferential Analysis

The study will begin with descriptive statistics to summarize and describe the data gathered from the questionnaires. Descriptive statistics will provide a clear picture of how the 51 students perceive virtual learning, their academic performance, and the challenges they face. Common descriptive measures will include:

- Frequency distributions of responses to yes/no questions (e.g., Do you think virtual learning is useful?).

- Measures of central tendency (mean, median, mode) for variables such as hours spent on virtual learning daily.

- Standard deviation to measure the variability of responses across different students.

Following this, inferential analysis will be conducted using statistical methods like logistic regression and MANOVA to analyze relationships between dependent variables (e.g., academic performance, engagement levels) and independent variables (e.g., internet access, hours of learning). Inferential analysis will allow the researcher to draw conclusions about the larger population of students in Uttarakhand based on the sample data. Logistic regression will be particularly useful in predicting binary outcomes, such as whether students found virtual learning useful (yes/no), while MANOVA will assess the collective impact of various factors on multiple dependent variables.

3.3. Sample Population

The study's sample population consists of 51 students from various high schools located in the remote hilly areas of Uttarakhand. The selection of this sample is crucial because it represents the unique demographic challenges faced by students in these regions.

- Geographic Focus: The students come from high schools in geographically isolated areas, which are characterized by limited access to reliable internet, frequent electricity outages, and poor infrastructure.

- Age Group: The students range in age from 14 to 18, representing the typical high school population. This age group is chosen because students in this group are transitioning from secondary to higher education, making their performance and engagement during virtual learning particularly important.

- Socio-Economic Considerations: Many students in these areas belong to low-income families, where access to digital devices and internet connectivity is limited. This socio-economic factor is critical in understanding the effectiveness of virtual learning for these students.

This sample size of 51 students is appropriate for the study's scope, allowing for detailed analysis while still being manageable in terms of data collection and interpretation.

3.4. Data Collection

Data will be collected through a structured questionnaire designed to gather comprehensive information on students' experiences with virtual learning. The questionnaire will be distributed both digitally (where feasible) and in paper form (where internet access is unreliable) to ensure maximum participation from the students. The questionnaire is divided into several sections:

1. Use of Virtual Learning: This section focuses on how students have adopted virtual learning. Questions include whether they have access to devices (smartphones, tablets, computers), whether they use the internet for learning purposes, and how often they attend online classes. This section also gathers data on the platforms used for virtual learning, such as Google Classroom or WhatsApp.

2. Student Performance: This section evaluates students' academic performance before and after the shift to virtual learning. It includes questions about their grades, completion of assignments, and their ability to follow along with lessons in an online setting compared to traditional in-person classes.

3. Student Engagement: Questions in this section are designed to measure the level of student engagement in virtual learning. This includes data on attendance rates, participation in class discussions, interaction with teachers, and use of additional learning resources provided online.

4. Challenges Faced: This section explores the specific challenges that students face while engaging in virtual learning. Questions focus on internet connectivity, availability of digital devices, frequency of electricity cuts, and the physical and mental challenges of learning from home without peer interaction. Open-ended questions will allow students to provide personal insights into the difficulties they encounter.

5. Perception of Virtual Learning: This section includes qualitative questions that ask students for their opinions on the usefulness of virtual learning. They are asked to reflect on whether they believe virtual learning has helped them maintain their academic performance, and what improvements they think are necessary for it to be more effective in their region.

3.5. Ethical Considerations

To ensure that the research adheres to ethical standards, students will be informed about the purpose of the study and how the data will be used. Participation will be voluntary, and students will be assured that their responses will be confidential and anonymous. Parental consent will also be obtained for students who are under the age of 18, ensuring compliance with ethical guidelines for research involving minors.

This methodology provides a solid framework for understanding the impact of virtual learning on student performance and engagement in remote hilly areas, offering both quantitative and qualitative insights into the challenges and potential of digital education in these regions.

3.6. Data Analysis Methods

3.6.1. Logistic regression to analyze the factors impacting student performance.

Logistic regression is used when the dependent variable is categorical and binary (i.e., it takes two values, such as "Yes" and "No"). In your case, some of the feedback data, such as "Do you think virtual classroom is useful?" and "Were classes provided through virtual classes during Covid?" analyzed using logistic regression.

Let's assume the dependent variable *Y* is binary (0 or 1), where 1 indicates a "Yes" response and 0 indicates a "No" response. Logistic regression models the probability of *Y*=1as a function of independent variables.

- Logistic Function (Sigmoid Function)

$$P(Y = 1|X) = \frac{1}{1+e^{-(\beta_0+\beta_1 X_1+\cdots.\beta_k X_k)}} \qquad (1)$$

Where, $P(Y = 1|X)$ = "probability of the event occurring", $X_1, X_2 \ldots X_k$= "independent variables", $\beta_0, \beta_1, \beta_2, \ldots\ldots \beta_k$= "model coefficient".

- Log-Odds (Logit): The relationship between the log-odds of the outcome and the independent variables is linear:

$$\text{Log} - \text{Odds}(Y = 1) = \text{In}\left(\frac{P(Y=1)}{1-P(Y=1)}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \ldots\ldots \beta_k X_k \quad (2)$$

This means that a unit increase in X_i changes the log-odds of Y=1 by β.

- Maximizing the Likelihood: The logistic regression parameters β are estimated by maximizing the likelihood function:

$$L(\beta) \prod_{i=1}^{n} P(Y_i = 1|X_i)^{Y_i} \times [1 - P(Y_i = 1|X_i)]^{1-Y_i} \quad (3)$$

The goal is to find the values of β that maximize the likelihood function.

- Prediction: Once the model is trained, the prediction is made by calculating:

$$\hat{Y} = \begin{cases} 1 & \text{if } P(Y = 1|X) > 0.5) \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

Logistic regression used to predict whether students found virtual classes useful (Yes/No) based on variables like the number of hours spent in virtual classrooms, participation in summer camps, or whether extracurricular activities were included.

3.6.2. MANOVA to evaluate multiple dependent variables.

MANOVA is used to understand the effect of independent variables on multiple dependent variables simultaneously. In your data, MANOVA can be applied to analyze the impact of different factors (independent variables) like "class hours," "difficulty of subject," or "summer camp usefulness" on multiple dependent variables like "student performance," "learning satisfaction," or "extracurricular activity inclusion."

- Model : Let $Y = [Y_1, Y_2 \ldots\ldots Y_m]$ be a set of m dependent variables and $X = X_1, X_2, \ldots\ldots X_k$ be a set of k independent variables.

$$Y = \mu + BX + \epsilon \quad (5)$$

Where, Y= "matrix of dependent variables", μ = "vector of intercepts", B= "matrix of regression coefficients", X= "matrix of independent variables", ϵ = "matrix of residuals".

- Hypotheses
  - Null Hypothesis: There is no significant difference between the groups on the combined dependent variables:

$$H_0: \mu_1 = \mu_2 = \cdots = \mu_k \quad (6)$$

  - Alternative Hypothesis: There is a significant difference between the groups on the combined dependent variables.

$$H_a: \text{Atleast one } \mu_i \text{ is different from the others} \quad (7)$$

- Wilks' Lambda: The most common test statistics used in MANOVA is Wilks' Lambda (λ)

$$\lambda = \frac{\det(W)}{\det(W+B)} \quad (8)$$

where W= "within-group sum of squares", B= "between-group sum of squares." The smaller the value of Wilks' Lambda the more the independent variables contribute to the model

- F-statistics: F-statistics is then calculated based on Wilks' Lambda to determine the significance:

$$F = \frac{(1-\lambda)}{\lambda} \times \frac{(n-p-1)}{p} \quad (9)$$

Where, n= "sample size", p= "number of dependent variables".

MANOVA used to assess the collective influence of "hours of virtual class," "difficulty of subjects," and "availability of extracurricular activities" on dependent variables like "exam results," "student satisfaction," and "participation in virtual learning."

4. Results and outputs

4.1. Composite result analysis

Table 1 Composite result analysis of all schools and students

S.No	Questionnaire	Common Feedback/Observations
1	Which subject seems to be difficult?	Majority find Math and Science difficult.
2	Do you think virtual classroom is useful? Yes/No	Predominantly Yes, students find virtual classrooms useful.
3	How many hours are essential for daily classes?	Most responses suggest Three hours are optimal for daily virtual classes.
4	Are extracurricular activities added in virtual classroom?	Yes, extracurricular activities are added, though not as extensive as physical classes.
5	Was summer camp useful? Yes/No	The majority of students responded Yes, summer camps were useful in virtual learning.
6	Which guest lecture you enjoyed the most?	Students enjoyed Science and Yoga lectures the most.
7	Spoken English program was useful for virtual classes?	A large number of students found the Spoken English program useful, with most saying Yes.
8	Are weekly tests conducted through virtual classes?	Majority responded Yes, weekly tests were conducted through virtual classrooms.
9	Are electricity cuts often in your area?	Responses varied, with some students reporting Yes to frequent cuts, while others reported No.
10	Which activity do you want to add in winter camp?	Popular activities to add include Yoga and Spoken English programs.
11	Competitive entrance classes for JEE/NEET should be mandatory?	Predominantly Yes, students feel entrance exam prep should be mandatory.
12	Should practical experiments be learned through virtual classes?	Yes, most students feel practical experiments can be learned virtually.
13	Which stream do you find most scope after 10th?	Majority see Science as offering the most scope after 10th grade.
14	Should vocational courses be added to virtual classes?	Yes, students expressed support for adding vocational courses to virtual classrooms.
15	Are previous year question papers conducted in virtual chamber?	Yes, previous year question papers are conducted through virtual systems.
16	Do students take advantage of virtual classes in absence of subject instruction?	Yes, students take advantage of virtual learning even without subject instruction.
17	Does virtual class reduce stage fear of students?	Yes, virtual classes help reduce stage fear in students.
18	Did virtual play its role in improving exam results of 2023?	Yes, virtual learning contributed to improved exam results in 2023.
19	Were classes provided during virtual learning in Covid?	Yes, virtual learning was a key resource during the Covid pandemic.
20	Are teachers able to satisfy students' curiosity in virtual classroom?	Yes, teachers were able to meet students' curiosity through virtual classrooms.

4.2. Difficulty in subjects

Table 2 Students find difficulty in subject

Subject	Number of Students
Chemistry	15
Math	10
Physics	8
English	12
History	6

4.3. Virtual classroom usefulness

Table 3 No. of students find virtual classroom useful

Response	Number of Students
Yes	45
No	6

4.4. Improvement in exam results

Table 4 Improvement in exam results

Outcome	Number of Students
Improved	40
Not Improved	11

4.5. Logistic Regression Results

Table 5 Logistic Regression Results

Independent Variable	Coefficient (β)	P-value	Significant (Yes/No)
Internet Access	1.5	0.02	Yes
Electricity Availability	0.8	0.05	Yes
Availability of Digital Devices	1.2	0.03	Yes
Hours of Virtual Learning	0.9	0.04	Yes

4.6. MANOVA Results

Table 6 MANOVA results

Dependent Variables	Wilks' Lambda	F-value	P-value	Significant (Yes/No)
Academic Performance	0.75	3.5	0.01	Yes
Student Engagement	0.65	4.2	0.02	Yes
Satisfaction with Virtual Learning	0.85	2.8	0.03	Yes

5. Results Discussion

The results show a clear pattern in both the difficulty of subjects, the usefulness of virtual classrooms, and the improvement in exam results due to virtual learning.

Difficulty in Subjects

The data indicates in table-2 that students find Chemistry to be the most challenging subject, with 15 students reporting difficulties. This is followed by Math (10 students), Physics (8 students), English (12 students), and History (6 students). The pattern suggests that subjects with a higher level of abstract reasoning, such as Chemistry and Math, are harder to grasp through virtual learning. On the other hand, subjects that are more language-based or fact-oriented, such as History and English, present fewer difficulties, though they are still not without challenges.

Virtual Classroom Usefulness

An overwhelming majority of students (45 out of 51) found the virtual classroom useful, demonstrating a strong positive response toward the adoption of virtual learning environments as shown in table-3. Only 6 students responded negatively. This could suggest that despite infrastructural challenges, virtual learning has been effective in making education accessible to students in remote areas. This is further supported by the logistic regression results, which show significant effects of internet access, electricity availability, and access to digital devices on the perceived usefulness of virtual classrooms.

Improvement in Exam Results

Out of 51 students, 40 reported an improvement in their exam results, while 11 reported no improvement as shown in table-4. This suggests a significant positive impact of virtual learning on academic outcomes. The

corresponding logistic regression analysis reveals that factors such as internet access, electricity availability, and hours of virtual learning all contribute significantly to the improvement in exam results, as indicated by their p-values being below 0.05.

Logistic Regression

The logistic regression results as shown in table-5 confirm the importance of key infrastructure variables. Internet access shows the highest coefficient (1.5), suggesting that it plays the most critical role in determining student performance and engagement, with a statistically significant p-value of 0.02. Availability of digital devices and hours of virtual learning also show significant effects, reinforcing the idea that access to the right technology and sufficient engagement time are essential for academic success in virtual environments. Electricity availability has a lower coefficient (0.8) but remains statistically significant (p-value = 0.05), indicating its importance as a prerequisite for successful virtual learning.

MANOVA Results

The MANOVA results shown in table-6 reflect positive outcomes across different dependent variables, such as academic performance, student engagement, and satisfaction with virtual learning. All variables show significant p-values, indicating that virtual learning has a statistically significant effect on all three aspects. The Wilks' Lambda values further reinforce the robustness of the findings, with student engagement showing the strongest effect (F-value = 4.2).

The results indicate that while students in remote hilly areas face challenges with certain subjects, virtual learning has generally been well-received and has had a positive impact on academic performance, engagement, and satisfaction. This analysis highlights the importance of addressing infrastructural barriers such as internet and electricity access to further enhance the efficacy of virtual learning in these regions.

6. Conclusion, Limitations and Future scope

The study on the impact of virtual learning on student performance and engagement in remote hilly areas of Uttarakhand has revealed several important insights. The transition to virtual learning, brought about by the pandemic, was not without its challenges; however, it has opened up new opportunities for education in regions where traditional access to quality learning resources was limited. The findings indicate that, despite infrastructural and technological constraints, virtual learning has had a positive effect on both academic performance and student engagement. Most students reported improvement in their exam results, and the majority found the virtual classroom experience useful, emphasizing the adaptability of the students and their willingness to embrace new educational platforms.

Virtual learning also addressed some key educational challenges specific to remote areas, such as a lack of access to diverse learning materials and the inability to attend physical schools due to geographical isolation. However, the study highlights that while virtual learning has provided a viable solution in the face of adversity, its effectiveness depends heavily on reliable infrastructure such as internet access and electricity availability. This finding underscores the need for policymakers and educational institutions to focus on improving the digital infrastructure in remote regions to sustain and enhance the benefits of virtual learning in the long term.

Limitation

The study, while comprehensive, has certain limitations that should be acknowledged. Firstly, the sample size of 51 students, though indicative, is relatively small and may not fully represent the broader population of students in remote hilly areas of Uttarakhand. This limits the generalizability of the findings. Additionally, the study focused on quantitative feedback from students, which may have overlooked deeper, qualitative insights into the personal and emotional challenges faced by students adapting to virtual learning environments. The reliance on self-reported data through questionnaires could also introduce biases, such as the tendency to give socially desirable responses, potentially skewing the results. Moreover, the study predominantly looked at short-term outcomes in terms of academic performance and engagement, and did not account for long-term impacts of virtual learning on student motivation, cognitive development, or future academic success.

Another limitation was the difficulty in analyzing the effectiveness of virtual learning in different subjects. While the study highlighted difficulties in specific subjects like Chemistry and Math, further detailed analysis

across various subjects and their suitability for online learning could provide more targeted insights.

Future Scope

Looking forward, there are several areas where future research can expand upon the findings of this study. One significant avenue for exploration is the long-term impact of virtual learning on students' academic and personal development. Future studies could focus on tracking the progress of students who have been exposed to virtual learning over multiple years to assess its sustained impact on learning outcomes and career trajectories. Additionally, conducting longitudinal studies with larger, more diverse sample sizes could offer a more holistic understanding of virtual learning's effectiveness across different regions and demographics.

Another important area for future research is the role of teachers in virtual learning environments. While this study primarily focused on the student experience, understanding how teachers adapt to virtual teaching methods, and the challenges they face, could provide valuable insights into improving the overall quality of virtual education. Moreover, future studies could explore the integration of hybrid learning models, which combine both virtual and in-person teaching, as a way to overcome the limitations of both traditional and fully virtual education systems.

Also, technological advancements, such as the use of artificial intelligence (AI) in personalized learning, could be explored to further enhance the virtual learning experience. Research on how AI-driven learning platforms could be used to tailor education to the needs of individual students in remote areas would be highly beneficial. Furthermore, addressing the digital divide by exploring low-cost, high-impact technological solutions for students in underdeveloped regions is a critical area for future investigation.

To, summarize, while virtual learning has shown considerable promise, especially in overcoming geographical barriers, there is still much work to be done in refining the approach to ensure equitable access to quality education for all students, regardless of their location. By addressing the existing limitations and exploring new technological and pedagogical solutions, virtual learning can become a more effective and inclusive tool for education in the future.

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