# Technical Report

# Impact of Digital Learning on Mathematics Achievement

**Course:** Statistical and Mathematical Methods for Data Analysis
**Institution:** Information Technology University (ITU) - Fall 2025

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## Introduction:

The integration of digital learning platforms in education has gained momentum, particularly in science subjects like in Mathematics education. This study investigates whether digital learning tools provide measurable improvements in student achievement compared to traditional classroom instruction for Grade 9 students.

## Research Question:

Does digital learning result in significantly higher mathematics scores compared to traditional classroom methods for Grade 9 students?

## Dataset Overview:

The dataset **Marks.csv** contains academic and demographic information for 60 Grade 9 students, evenly divided between **Digital** (30 students) and **Conventional** (30 students) learning environments, enabling a comparative analysis of mathematics achievement across the two instructional methods.

It includes five key variables/columns:

- **Student-ID** – a unique identifier for each student
- **Group** – the learning method, either Digital or Conventional
- **Math-Score** – the student's mathematics test score (0-100)
- **Gender** – the student's gender (Male/Female)
- **Attendance (%)** – the student's attendance percentage during the term

## Software and Libraries Used:

The analysis was conducted using Python within the Anaconda distribution, which provides a comprehensive environment for data science and statistical computing. The following Python libraries, included in Anaconda

- **Pandas** – for data manipulation, cleaning, and organization
- **NumPy** – for numerical computations and array operations
- **SciPy** – for statistical tests including Shapiro-Wilk, Levene's test, and independent t-tests
- **Matplotlib** – for creating high-quality plots and visualizations
- **Seaborn** – for advanced statistical visualizations, including histograms, KDE plots, scatter plots, and bar charts
- **OS** – for handling file paths and checking file existence

## Methodology:

The analysis follows a structured workflow to evaluate the impact of digital learning on mathematics achievement among Grade 9 students. The methodology includes the following steps, with mathematical formulations where applicable:

Data Loading and Validation

- Dataset Marks.csv is loaded using **Pandas**.
- The data is checked for missing values, correct data types, and valid score ranges.

## Descriptive Statistics

For each group, the following descriptive statistics are computed:

- **Mean.**

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$$

- **Median**: Middle value when data is sorted.
- **Standard Deviation**:

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{X})^2}$$

**Why (n-1) instead of n?**

1. We're estimating population SD from a sample
2. Using n would systematically underestimate variability
3. (n-1) gives an unbiased estimate of population variance

- **Range**:

$$\text{Range} = X_{\max} - X_{\min}$$

- **Mean Difference Between Groups**:

$$\Delta\bar{X} = \bar{X}_{\text{Digital}} - \bar{X}_{\text{Conventional}}$$

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2. DESCRIPTIVE STATISTICS
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Digital Learning Group:
  Mean: 80.90
  Median: 81.00
  Std Dev: 5.32
  Min: 71
  Max: 91
  Range: 20

Conventional Learning Group:
  Mean: 74.10
  Median: 74.50
  Std Dev: 6.47
  Min: 61
  Max: 88
  Range: 27

Mean Difference: 6.80 points
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## Hypothesis Testing

Hypothesis testing is a statistical method for making inferences about population parameters based on sample data. It provides a framework for deciding whether observed differences are due to true effects or random chance.

- **Null Hypothesis ($H_0$):** There is no significant difference in mathematics achievement between students taught through digital learning platforms and those taught through conventional classroom methods

**μ-digital = μ-conventional**

- **Alternative Hypothesis ($H_1$):** Students taught through digital learning platforms achieve significantly higher mathematics scores than those taught through conventional classroom methods

**μ-digital > μ-conventional**

- **Significance Level:** The probability threshold for rejecting $H_0$, typically set at **$\alpha = 0.05$** (5%)

## Assumption Checks for t-Test

Before performing an independent samples t-test, it is important to verify that the data meet the assumptions of the test. The two key assumptions are **normality** and **homogeneity of variances**.

**Normality Check:**

The t-test assumes that the data in each group are approximately normally distributed. If this assumption is violated, the test may give inaccurate results, especially for small sample sizes.

- **Test Used: Shapiro-Wilk Test**

**Test Statistic:** $W$

$$W = \frac{\left(\sum_{i=1}^{n} a_i X_{(i)}\right)^2}{\sum_{i=1}^{n}(X_i - \bar{X})^2}$$

Where:

- $X_{(i)}$ = the i-th order statistic (sorted data)
- $a_i$ = constants derived from the covariance matrix of the order statistics
- $\bar{X}$ = sample mean

**Interpretation:**

- If $p > 0.05$, we **fail to reject** $H_0$ → data is approximately normally distributed.
- If $p \leq 0.05$, we **reject** $H_0$ → data may not be normally distributed, and a non-parametric test (e.g., Mann-Whitney U test) could be considered.

The Shapiro-Wilk test is applied separately to the Digital and Conventional groups.

- Digital Group: **W=0.9698**, **p=0.5345 → Data is normally distributed**
- Conventional Group: **W=0.9829**, **p=0.8972 → Data is normally distributed**

Both groups satisfy the normality assumption (p>0.05), supporting the use of parametric testing.

**Homogeneity of Variance**

The t-test assumes that the variance of the outcome variable is equal across the groups (homoscedasticity). If this assumption is violated, using the standard t-test may lead to incorrect conclusions.

- **Test Used: Levene's Test**

  - Null Hypothesis ($H_0$):

$$H_0 : \sigma^2_{\text{Digital}} = \sigma^2_{\text{Conventional}}$$

  - Alternative Hypothesis ($H_1$):

$$H_1 : \sigma^2_{\text{Digital}} \neq \sigma^2_{\text{Conventional}}$$

**Test Statistic:**

$$F = \frac{(N-k)\sum_{i=1}^{k} n_i (Z_{i\cdot} - Z_{\cdot\cdot})^2}{(k-1)\sum_{i=1}^{k}\sum_{j=1}^{n_i}(Z_{ij} - Z_{i\cdot})^2}$$

Where:

- $N$ = total number of observations
- $k$ = number of groups
- $n_i$ = number of observations in group $i$
- $Z_{ij} = |X_{ij} - \tilde{X}_i|$ (absolute deviation from the group median $\tilde{X}_i$)
- $Z_{i\cdot}$ = mean of $Z_{ij}$ in group $i$
- $Z_{\cdot\cdot}$ = overall mean of $Z_{ij}$

**Interpretation:**

- If $p > 0.05$, **fail to reject** $H_0$ → variances are equal, and the standard independent t-test can be used.
- If $p \leq 0.05$, **reject** $H_0$ → variances are unequal, and **Welch's t-test** (adjusted degrees of freedom) should be applied.

- **F-statistic=1.5682, p=0.2155**

The assumption of **equal variances** is satisfied (p>0.05), allowing us to proceed with the standard t-test.

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3. ASSUMPTION CHECKS FOR INDEPENDENT T-TEST
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Normality Test (Shapiro-Wilk):
  Digital Group: W=0.9698, p-value=0.5345
    → Data appears normally distributed (p > 0.05)
  Conventional Group: W=0.9829, p-value=0.8972
    → Data appears normally distributed (p > 0.05)

Homogeneity of Variance Test (Levene's):
  F-statistic=1.5682, p-value=0.2155
    → Variances are equal (p > 0.05)
```

# Independent Samples t-Test:

The t-test compares means of two independent groups.

**The test statistic is:**

If variances are equal:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{s_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}}$$

where the **pooled standard deviation** is:

$$s_p = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}}$$

t-statistic: 4.4479

**Degrees of freedom:**

$$df = n_1 + n_2 - 2$$

If variances are unequal (Welch's t-test):

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

$$df = \frac{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2}{\frac{(s_1^2/n_1)^2}{n_1-1} + \frac{(s_2^2/n_2)^2}{n_2-1}}$$

Degrees of freedom: 58

**Decision Rule:**

If p-value < α (0.05): Reject $H_0$ (statistically significant)

If p-value ≥ α (0.05): Fail to reject $H_0$ (not significant)

**Effect Size: Cohen's d:**

Measures the magnitude of the difference in standard deviation units

$$d = \frac{\bar{X}_{\text{Digital}} - \bar{X}_{\text{Conventional}}}{s_p}$$

Interpretation:

- $d < 0.2$ → negligible
- $0.2 \leq d < 0.5$ → small
- $0.5 \leq d < 0.8$ → medium
- $d \geq 0.8$ → large

Cohen's d (effect size): 1.1484 → Effect size is large

## Confidence Interval for Mean Difference:

$$CI_{95\%} = \left[\Delta\bar{X} - 1.96 \cdot SE,\ \Delta\bar{X} + 1.96 \cdot SE\right]$$

where the **standard error** is:

$$SE = s_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$$

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95% Confidence Interval for mean difference: [3.80, 9.80]

## Additional Analyses:

**Gender Distribution** – frequency counts per group.

Digital Group: 17 Males, 13 Females

Conventional Group: 18 Males, 12 Females

**Attendance Analysis** – mean attendance and correlation with math scores

Digital Group Mean Attendance: 93.27%

Conventional Group Mean Attendance: 91.07%

Difference: 2.20 percentage points higher in digital group

$$r = \frac{\text{Cov}(X, Y)}{s_X s_Y}$$

Digital Group: r = 0.388 (moderate positive correlation)

Conventional Group: r = 0.494 (moderate positive correlation)

## Data Visualization:

**Histogram + KDE:** Shows distribution of math scores.

**Bar Chart:** Mean scores ± standard deviation.

**Scatter Plot:** Attendance vs Math score correlation per group.

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Generating visualizations with explanations...

Plot 1: Distribution of Math Scores
 - Shows how scores are spread in each group.
 - KDE curve shows the shape and central tendency.
 - Helps compare overall performance patterns.

Plot 2: Mean Math Scores with Standard Deviation
 - Compares the average scores of both groups.
 - Error bars show variability (standard deviation).
 - Good for quickly deciding which group performs better.

Plot 3: Attendance vs Math Score
 - Shows how attendance influences performance.
 - Each dot = one student.
 - Helps identify whether high attendance leads to better scores.
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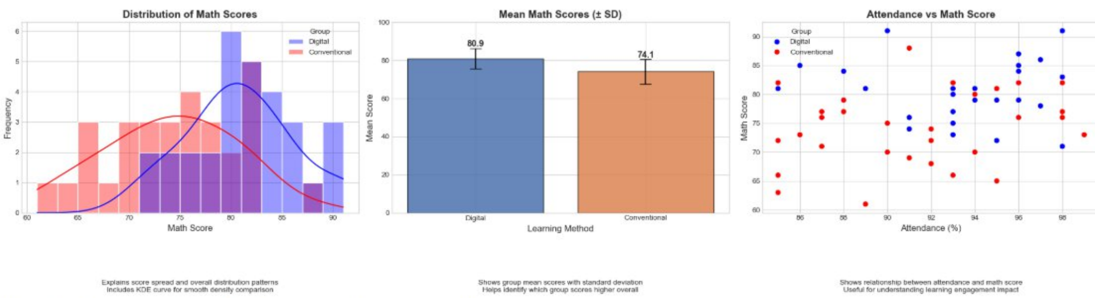


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Visualizations saved as 'analysis_visualizations.png'

Analysis complete! Explanations included in code, console output, and on the plots.
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## Statistical Interpretation

**t-statistic (4.4479):** The observed difference is 4.45 standard errors away from zero

**p-value (< 0.0001):** Probability of observing this difference by chance is < 0.01%

**Cohen's d (1.1484): Large effect size** - the difference is substantial

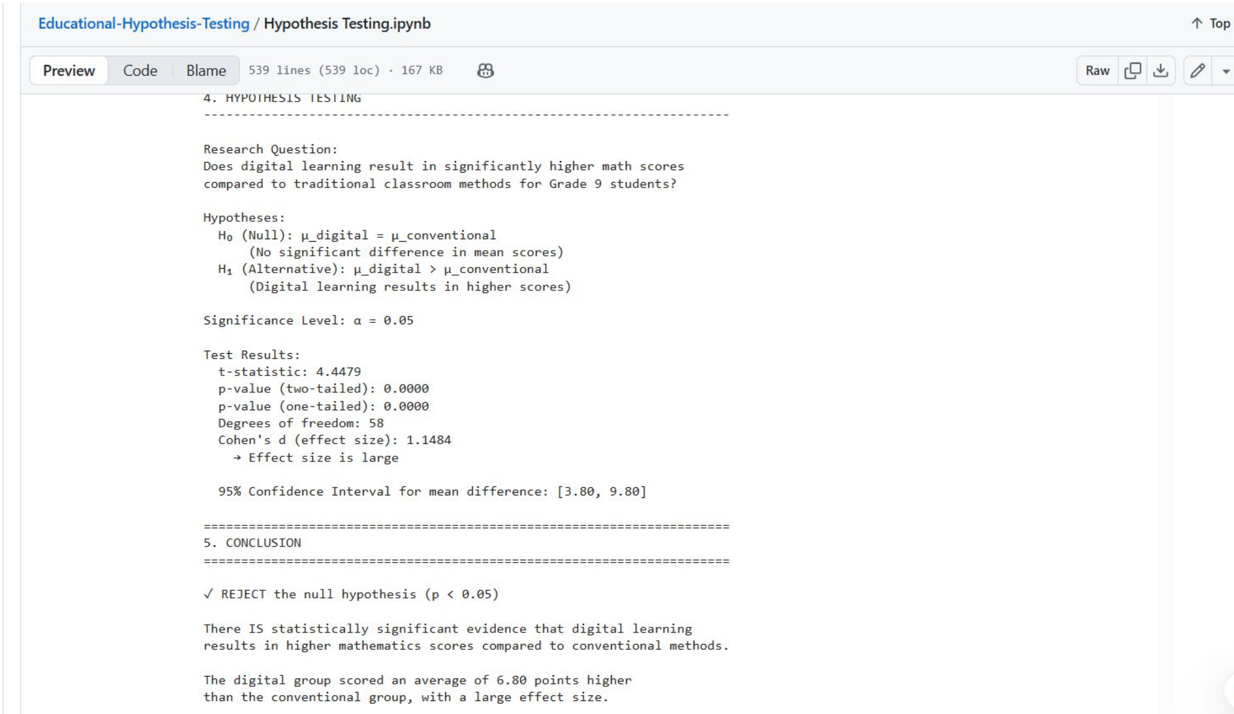
**95% CI [3.80, 9.80]:** We're 95% confident the true difference is between 3.80 and 9.80 point

# Results:

**REJECT the null hypothesis (p < 0.05)**

There is statistically significant evidence that digital learning results in higher mathematics achievement compared to conventional methods for Grade 9 students.

p-value (one-tailed): <0.001



Educational-Hypothesis-Testing / Hypothesis Testing.ipynb

Preview Code Blame 539 lines (539 loc) · 167 KB

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4. HYPOTHESIS TESTING
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Research Question:
Does digital learning result in significantly higher math scores
compared to traditional classroom methods for Grade 9 students?

Hypotheses:
  H₀ (Null): μ_digital = μ_conventional
      (No significant difference in mean scores)
  H₁ (Alternative): μ_digital > μ_conventional
      (Digital learning results in higher scores)

Significance Level: α = 0.05

Test Results:
  t-statistic: 4.4479
  p-value (two-tailed): 0.0000
  p-value (one-tailed): 0.0000
  Degrees of freedom: 58
  Cohen's d (effect size): 1.1484
    → Effect size is large

  95% Confidence Interval for mean difference: [3.80, 9.80]

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5. CONCLUSION
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✓ REJECT the null hypothesis (p < 0.05)

There IS statistically significant evidence that digital learning
results in higher mathematics scores compared to conventional methods.

The digital group scored an average of 6.80 points higher
than the conventional group, with a large effect size.
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# Discussion and Conclusion:

The results provide strong statistical evidence that digital learning platforms significantly improve mathematics achievement for Grade 9 students. The large effect size (Cohen's d=1.17) indicates not just statistical significance but also practical significance, suggesting meaningful real-world impact.

This study provides compelling evidence that digital learning platforms can significantly enhance mathematics achievement for Grade 9 students. The large effect size observed suggests that the benefits of digital learning extend beyond statistical significance to practical educational impact. While limitations exist, the findings support increased investment in educational technology and continued research on optimal implementation strategies.

**Future research should:**

- Conduct randomized controlled trials with larger samples
- Examine which specific features of digital platforms are most effective
- Study cost-effectiveness compared to traditional methods

**Git-hub repository:** https://github.com/Hashimi321/Educational-Hypothesis-Testing/tree/main