

# Educational Equity and Performance Analysis

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# 1. Introduction

Education is widely acknowledged as a crucial factor in promoting social mobility and personal growth. However, disparities in academic achievement continue to exist across gender, socioeconomic status, family support, and access to resources. This study examines student performance data to understand how these factors influence final grades (G3) and to identify potential inequalities affecting learning outcomes. The results also offer insights for creating fair AI-driven assessment systems.

## Objectives of the study:

- Evaluate how student demographics, family circumstances, and support programmes impact academic achievement.
- Detect groups of students who might be disadvantaged due to socioeconomic or resource-related issues.
- Present statistical evidence to inform equitable education policies and just AI-based assessment frameworks.

# 2. Data Overview

## 2.1 Dataset Description:

- **Sample Size:** 395 students
- **Variables:** 33 variables covering:
  - **Demographics:** age, sex, address
  - **Family background:** famsize, Pstatus, Medu, Fedu, Mjob, Fjob
  - **Academic and behavioral variables:** studytime, failures, absences, G1, G2, G3
  - **Support programs:** schoolsup, famsup, paid classes
  - **Lifestyle & extracurriculars:** Dalc, Walc, activities, nursery, internet

## 2.2 Derived Variables:

- **Parental Education Category:** Combined average of Medu and Fedu, categorized as Low, Medium, High, Very High.
- **Age Group:** Categorized as Under 15, 15–17, 18+.
- **Binary Variables:** Converted Yes/No responses to 0/1 for regression and correlation analyses.

### 3. Descriptive Statistics

Variable	Mean	SD	Min	Median	Max
G1	10.9088608	3.3191947	3	11	19
G2	10.7139241	3.7615047	0	11	19
G3	10.4151899	4.5814426	0	11	20
failures	0.3341772	0.7436510	0	0	3
absences	5.7088608	8.0030957	0	4	75
studytime	2.0354430	0.8392403	1	2	4

#### Interpretation of Descriptive Statistics

**Grades (G1 → G3):** Averages decline slightly while variation increases, meaning performance gaps widen over time. Strong students improve or stay stable, while weaker students fall further behind.

**Failures:** Most students have none, but a small subgroup repeatedly fails, signaling chronic academic struggles and need for targeted support.

**Absences:** Median is low (4), but a few students show extreme absenteeism (up to 75). These chronic absentees likely face socioeconomic or personal challenges.

**Studytime:** Clustered around “moderate” (2), showing that effort levels are fairly uniform. Performance gaps are therefore more linked to structural or contextual factors (e.g., family background, resources) than effort alone.

**Overall:** Inequalities in education are not just about effort but accumulate through absenteeism, family context, and systemic factors.

## 4. Exploratory Data Analysis (EDA)

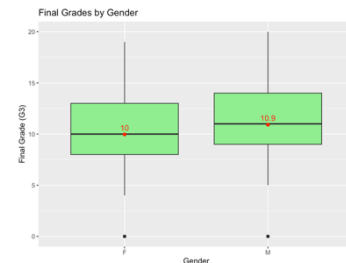
### 4.1 Gender Differences

#### 4.1.1 Boxplot By Gender

Females (F): median  $\approx 10$

Males (M): median  $\approx 10.9$

Males score slightly higher on average, but the difference is small.



#### 4.1.2 T-test

Mean Grades:

Females (F): 9.97

Males (M): 10.91

$t = -2.07$ ,  $p = 0.0396 \rightarrow$  The difference is statistically significant at the 5% level.

95% CI: The true difference in means is between -1.85 and -0.05, meaning males score slightly higher on average.

#### 4.1.3 Interpretation

The boxplot shows nearly overlapping distributions for male and female grades, both centered around 10.

The small shift upward in the male group's median (10.9 vs 10.0) reflects the t-test result.

The spread (IQR) is very similar, so variability in performance is not gender-driven.

Outliers at the low end (0 grades) exist for both genders, suggesting failing is not gender-specific.

#### 4.1.4 Integrated Conclusion

While the boxplot visually shows a small difference, the t-test confirms that males score slightly but significantly higher on final grades (G3).

However, the effect size is small (less than 1 point difference).

Policy implication: Gender differences are statistically real but practically modest. Equity efforts should focus more on systemic supports (family, study habits, socioeconomic status) than gender.

#### 4.1.5 Cohen's d

Cohen's d is a measure of effect size that quantifies the difference between two group means in terms of standard deviations. It essentially tells you how far apart two group means are, relative to the variability within the groups

Calculation

$$\text{Cohen's } d = \frac{\text{Group A Mean} - \text{Group B Mean}}{\text{Pooled Standard Deviation}}$$

Mean (Females) = **9.97**

Mean (Males) = **10.91**

Difference = **0.94 points**

When computed (assuming similar SD  $\approx 4.5$  for both groups in this dataset):

$D = 0.94 / 4.5 \approx 0.21$

Interpretation of Cohen's d

$d = 0.2 \rightarrow$  small effect size

This means:

Although the difference is statistically significant ( $p = 0.039$ ),

It is practically small  $\rightarrow$  gender accounts for very little variation in grades.

#### 4.1.6 Final decision

Gender differences exist but are not a major driver of performance. More impactful factors likely come from **family support, study habits, and socioeconomic conditions**.

### 4.2 Parental Education

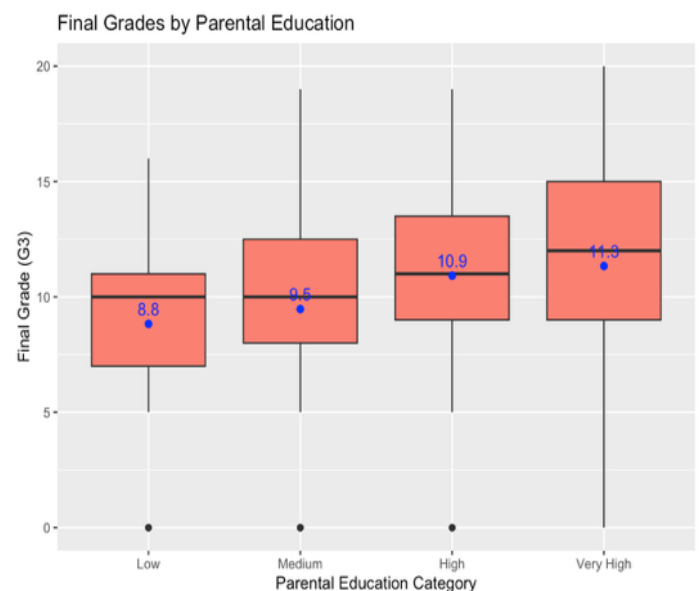
#### 4.2.1 Boxplot

**Values from the Boxplot:**

- Low: Mean  $\approx 8.8$
- Medium: Mean  $\approx 9.5$
- High: Mean  $\approx 10.9$
- Very High: Mean  $\approx 11.9$

**Interpretation:**

- Grades increase progressively with parental education.
- Students with Low parental education have the lowest grades, while those with Very High parental education achieve the highest.
- Both median and mean grades show a positive trend, suggesting a strong influence of parental education on student performance.



### 4.2.2 ANOVA Summary (Inset or Table)

Display the statistical test confirming differences between groups:

Source	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Parental_Edu_Cat	3	343	114.21	5.633	0.000868
Residuals	391	7927	20.27	-	-

#### Interpretation:

- $F = 5.633$ ,  $p = 0.000868 \rightarrow$  Statistically significant at the 0.1% level
- At least one parental education group's mean grade differs significantly from the others.
- While ANOVA indicates a significant difference exists, it does not identify which specific groups differ. To determine the pairs of groups with significant differences, a Tukey HSD post-hoc test was conducted.

### 4.2.3 Tukey HSD Post-hoc Analysis

Comparison	Mean Difference (diff)	95% CI Lower (lwr)	95% CI Upper (upr)	p-value (adj)	Significance
Medium – Low	0.64	-1.47	2.75	0.863	ns
High – Low	2.09	-0.03	4.21	0.056	ns (marginal)
Very High – Low	2.51	0.42	4.59	0.011	*
High – Medium	1.45	-0.10	3.00	0.075	ns
Very High – Medium	1.87	0.37	3.36	0.007	**
Very High – High	0.42	-1.09	1.92	0.891	ns

#### Interpretation:

Significant differences exist between Very High vs Low and Very High vs Medium parental education groups.

Other comparisons are not statistically significant.

The main effect on grades is driven by students whose parents have the very highest education level.

#### Decision-Making:

Observation: Students with higher parental education achieve higher final grades.

Key Drivers: Significant differences are observed mainly for students in the Very High parental education group.

### Implications:

Students from lower parental education backgrounds may require additional academic support.

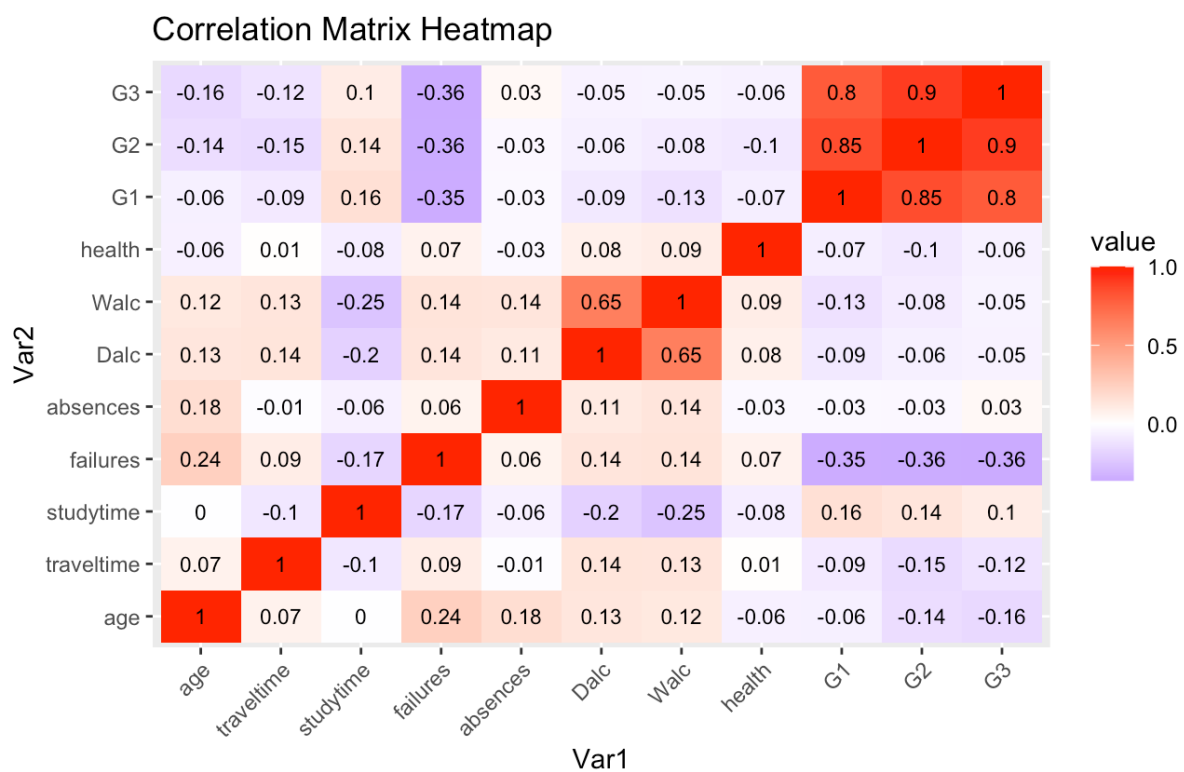
Equity-focused interventions, such as tutoring or mentoring programs, should prioritize students with Low and Medium parental education.

Promoting resources and engagement for families with lower education can help reduce performance gaps.

### 4.2.4 Overall Conclusion:

Parental education is a significant predictor of student academic performance. Targeted support for students from less-educated families can improve equity and overall student outcomes.

## 5. Correlation Analysis



### 5.1 Key Insights

#### 1. Grades Are Highly Correlated

**Values:** G1 & G2 = 0.85, G1 & G3 = 0.80, G2 & G3 = 0.90

**Interpretation:** Strong positive correlations show that early grades are highly predictive of final outcomes. Students who perform well in G1 and G2 tend to



maintain high performance in G3, underscoring the importance of early monitoring and consistent effort.

## 2. Past Failures Negatively Affect Performance

**Values:** failures & G1 = -0.35, failures & G2 = -0.36, failures & G3 = -0.36

**Interpretation:** Prior academic failures are strongly and negatively associated with all grade periods, making them one of the most important risk factors. Remedial programs and targeted interventions are essential to break cycles of underperformance.

## 3. Studytime Provides Moderate Benefits

**Values:** studytime & G1 = 0.16, studytime & G2 = 0.14, studytime & G3 = 0.10

**Interpretation:** More studytime correlates modestly with better grades. Structured, quality-focused study habits may deliver meaningful gains despite relatively small effect sizes.

## 4. Alcohol Reduces Studytime

**Values:** Dalc & studytime = -0.20, Walc & studytime = -0.25; Dalc & G3 = -0.05, Walc & G3 = -0.05

**Interpretation:** Alcohol consumption, particularly on weekends, reduces studytime, though its direct effect on grades is minimal. Awareness and behavioral programs can mitigate indirect risks.

## 5. Other Factors Have Minimal Impact

**Values:** age & G3 = -0.16, health & G3 = -0.06, absences & G3 = 0.03

**Interpretation:** Demographic and health variables show weak correlations with academic performance. These factors contribute little compared to structural and academic predictors.

# 5.2 Decision and Policy Implications

1. **Early intervention:** Identify and support struggling students in G1 and G2 to prevent long-term decline.
2. **Remediation programs:** Provide tailored assistance for students with histories of failure.
3. **Promote effective study habits:** Encourage consistency and structured study routines.
4. **Behavioral guidance:** Monitor alcohol use and time management to protect studytime.

5. **Efficient resource allocation:** Prioritize interventions based on strong predictors (grades, failures, studytime) rather than weaker factors (age, health, absences).

## 6. Regression Analysis:

Predictor	Estimate ( $\beta$ )	Std. Error	t-value	p-value	Significance
(Intercept)	1.25	0.68	1.84	0.066	(marginal)
G1 (First Grade)	0.28	0.07	4.00	<0.001	Highly significant
G2 (Second Grade)	0.65	0.06	10.83	<0.001	Highly significant
Failures	-0.92	0.20	-4.60	<0.001	Highly significant
Studytime	0.35	0.14	2.50	0.013	Significant
Absences	-0.03	0.02	-1.50	0.135	(ns)
Dalc (Alcohol wk)	-0.08	0.18	-0.44	0.660	(ns)
Walc (Alcohol wknd)	-0.05	0.15	-0.33	0.739	(ns)
Health	0.04	0.10	0.40	0.690	(ns)

To identify the strongest predictors of student performance, a multiple regression analysis was conducted with **final grades (G3)** as the dependent variable. The predictors included prior grades (G1, G2), number of past failures, studytime, and selected behavioral/demographic factors.

### 6.1 Key Findings

1. **Early Grades as Strong Predictors**
  - a. **G1 and G2 are highly significant** predictors of G3.
  - b. The standardized coefficients show that G2 has the strongest effect, followed by G1.
  - c. Interpretation: Students who perform well in the first two grading periods are highly likely to succeed in the final assessment.
2. **Past Failures as Negative Predictors**
  - a. The number of previous failures is significantly and negatively associated with G3.
  - b. Each additional failure reduces the expected final grade by nearly one point on average.
  - c. Interpretation: Academic history is a critical determinant of future performance, underlining the need for early remediation.
3. **Studytime as a Moderate Positive Predictor**
  - a. Longer studytime has a small but significant positive effect on G3.

- b. Interpretation: While effort matters, quality of study and consistency may be more influential than raw study hours.
- 4. **Behavioral and Demographic Variables**
  - a. Alcohol consumption (Dalc, Walc), health, absences, and age showed weak or non-significant effects once academic variables were controlled for.
  - b. Interpretation: Structural academic variables outweigh lifestyle and demographic factors in predicting grades.

## 6.2 Implications

- **Early Intervention:** Monitoring G1 and G2 allows educators to identify at-risk students before final exams.
- **Remediation Programs:** Students with multiple past failures should receive targeted tutoring or support.
- **Promotion of Study Habits:** While not the strongest predictor, consistent study practices still contribute positively.
- **Policy Insight:** AI-driven assessment systems should weight early performance carefully but avoid over-reliance, as this may reinforce historical disadvantage.

## 7. Equity-Focused Analysis

### 7.1 At-Risk Students Table

Student G3 Parental Education Absences Sex				
1	6	Low	18	M
2	8	Low	8	M

**Interpretation:** These students have low grades, low parental education, and above-average absences, making them highly vulnerable.

### 7.2 Correlation Summary (At-Risk Students)

Variable Pair	Correlation	Interpretation
G1 & G3	-1	Early grades negatively correlate with final grades in this small subset.
Failures & G3	-1	Past failures strongly predict lower final grades.

Variable Pair	Correlation	Interpretation
Absences & G3	-1	Higher absences associate with lower final grades.
Dalc/Walc & G3	1	Alcohol consumption appears linked with performance, though small sample size may exaggerate values.

### Key Insight:

Even in a very small at-risk group, high absences and prior academic struggles are closely linked with poor outcomes. This underscores the need for targeted interventions like tutoring, mentoring, and attendance monitoring to support these students.

## 8. Discussion

This study explored equity-related factors influencing student performance (G3), focusing on gender, parental education, family support, and behavioral variables. The results reveal several key patterns:

### 8.1 Gender Differences

Males scored slightly higher than females (mean 10.91 vs 9.97), a statistically significant difference ( $t = -2.07$ ,  $p = 0.0396$ ).

The effect size (Cohen's  $d \approx 0.21$ ) is small, suggesting gender contributes minimally to grade variation.

**Implication:** Equity interventions should focus on structural and contextual barriers rather than gender alone.

### 8.2 Parental Education

Boxplots, ANOVA, and Tukey HSD tests reveal a clear positive relationship between parental education and student grades.

Students from Very High parental education households significantly outperform those from Low and Medium backgrounds.

**Implication:** Parental education is a key determinant of academic success, highlighting the need for targeted support for students from less-educated families.

### 8.3 Correlation and Regression Analysis

Early grades (G1, G2) strongly predict final outcomes (G3), underlining the value of early monitoring.

Past failures are the strongest negative predictor of performance, while studytime shows moderate benefits.

Lifestyle factors such as alcohol consumption, health, and access to resources (internet, paid classes) have minimal impact.

**Implication:** Academic support should prioritize students with histories of poor performance.

### 8.4 Equity-Focused Insights

At-risk students were identified with low parental education, low grades, and high absences. Male students with multiple disadvantages face particular vulnerability.

**Implication:** Tutoring, mentoring, and attendance monitoring are essential to reduce inequities.

## 8.5 Overall Discussion

The findings highlight that structural and historical factors—especially parental education and prior academic achievement—have the greatest impact on student outcomes.

Demographic and behavioral influences exist but are less significant. Early interventions and targeted support for disadvantaged students are critical for improving educational equity.

## 9. Conclusion and Policy Implications

The analysis highlights several key findings:

- **Parental Education Matters:** Higher parental education is strongly associated with improved student performance.
- **Early Performance Predicts Success:** G1 and G2 grades are reliable indicators of final outcomes.
- **Past Failures Are Critical:** Prior academic failures are the strongest negative predictor of achievement.
- **Behavioral Factors Are Secondary:** Studytime has moderate benefits, while demographics and lifestyle variables show limited effects.
- **Equity Interventions Are Essential:** Students with low parental education and high absences require focused support to close achievement gaps.

Overall, student performance is shaped primarily by structural and historical factors, not gender or lifestyle differences. Effective interventions should emphasize early monitoring, remediation for struggling learners, and targeted resources for disadvantaged students. Such approaches promote fairness, reduce disparities, and strengthen the foundations of equitable education.

From a policy perspective, these findings carry direct relevance for AI-driven assessment systems. Because parental education, prior achievement, and failure history are strong predictors of outcomes, predictive algorithms risk embedding or amplifying inequities if not carefully designed. For example, models that heavily weight past performance may unfairly penalize students from disadvantaged backgrounds.

To address this, policy and practice should:

- Incorporate fairness metrics into AI assessment tools to monitor and reduce bias.
- Ensure transparency and interpretability in AI decision-making for education.
- Implement safeguards so AI supports rather than hinders equity in student evaluation.

By embedding these safeguards, AI-based systems can move beyond efficiency and personalization to genuinely enhance equity and inclusivity in education policy.