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Behavioral Dynamics of Student Alcohol Use: A Markov Chain Analysis of Academic-Period Transitions

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Abstract. Alcohol consumption among secondary school students carries significant risks to academic performance and long-term health. While prior studies have already established static correlations between drinking behaviors and grades, the temporal dynamics of behavioral transitions remain unexplored. This study employs a Markov chain model to analyze students' drinking patterns across different academic periods (G1–G3), using a dataset of from Kaggle and the UCI Machine Learning Repository. This data contains students' Portuguese and math grades, as well as their weekdays and weekends' alcohol consumption. This study also quantifies transitions between drinking states (low/moderate/high), examining gender and weekday-weekend disparities, and assessing academic impacts through ANOVA and linear regression. The key findings reveal that, Male students exhibit persistent high-risk drinking states on weekends (male=3 vs. females=2), with a 70% retention probability in Markov transitions. Each 1-level increase in weekend drinking correlates with a 0.35-point grade decline (p-value < 0.001). Weekday drinking is uniformly low (level 1) across all students, suggesting academic routines suppress consumption.

Keywords: Alcohol consumption, Markov chains, Gender differences

1. Introduction

Alcohol consumption among adolescents is a persistent public health concern, with well-documented associations to cognitive impairment, risky behaviors, and diminished academic achievement [1,2]. While cross-sectional studies have established static correlations between drinking frequency and grades [3,4], these approaches fail to capture a critical dimension: how students transition between drinking states (e.g., from moderate to heavy use) across academic periods. This gap limits the ability of educators and policymakers to design timely, targeted interventions.

The study addresses this by applying Markov chain modeling—a dynamic analytical framework increasingly used in public health behavioral analysis [5], to longitudinal data on Portuguese and math students (G1–G3). We focus specifically on two unresolved aspects:

• Temporal dynamics: How weekday vs. weekend drinking patterns evolve during key academic stages, acknowledging that consumption is highly context-dependent [6].

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• Gender disparities:Why male students exhibit higher-risk trajectories, particularly on weekends [7].

Prior research has relied heavily on static snapshots, such as annual surveys linking binge drinking to GPA declines. However, these designs cannot answer pivotal dynamic questions: Are transitions between drinking states predictable? Do academic workloads interact with drinking cycles? Our Markov chain approach reveals these behavioral pathways, offering schools actionable insights. For instance, we identify weekends as "high-risk windows" where male students are significantly more likely to initiate and sustain heavy drinking—a pattern obscured in prior static work [8].

By integrating the dataset from Kaggle and the UCI Machine Learning Repository, which covering Portuguese and math students—we provide a data-driven framework to predict behavioral trajectories and inform policy. Our findings reveal that weekend drinking (particularly among males) is a high-risk state with long-term academic consequences, while weekdays exhibit uniformly low consumption, suggesting academic routines may suppress drinking. Also, we have found other correlations based on students' alcohol consumption. Also, we have done the ANOVA test as well as the linear regression analysis, and the result indicates that students' alcohol consumption indeed have a significant impact on their academic performance, which aligns with the basic fact. This study makes three key advances:

• Methodological: Introducing Markov chain analysis to model drinking behavior as a time-dependent process, rather than a static process.

• Empirical: Using ANOVA test and linear regression analysis to qualify the significance of alcohol consumption in students' academic performance, as well as the gender disparities.

• Practical: Revealing the negative impact of alcohol consumption on secondary students' daily lives.

Together, these contributions provide a dynamic, actionable framework for mitigating alcohol-related academic decline in educational settings.

2. Data-processing

2.1. Variable pre-processing

This study utilizes a dataset sourced from the Kaggle to analyze the relationship between alcohol consumption and academic performance in secondary school students. The dataset is available at: https://www.kaggle.com/datasets/uciml/student-alcohol-consumption. The dataset comprises student performance metrics and social behavior records from two distinct courses: Mathematics and Portuguese. It captures demographic, academic, and behavioral variables across three academic periods (G1, G2, G3). The primary variables of interest for this analysis are:

• Independent Variables: Alcohol consumption (separated into weekday (Dalc) and weekend (Walc) consumption on a 1-5 scale), student gender, and course type.

• Dependent Variable: The final grade, representing the student's academic outcome.

To ensure the analysis focused on the most relevant factors, variables were selected from four overarching categories present in the original dataset:

• Demographic Data: Age, gender were retained.

• Drinking Behavior: Weekend and weekday alcohol consumption levels.

• Academic Performance: Grades from all three periods (G1, G2, G3) were included.

Variables related to family background were excluded from this specific analysis as they were deemed less directly relevant to the core research questions concerning immediate behavioral

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patterns.

The dataset was cleaned to handle missing values and ensure consistency. All alcohol consumption metrics were treated as ordered categorical variables for the Markov chain analysis and as continuous variables for regression modeling.

2.2. Analytical framework

The processed data was analyzed using a dual-method approach in R to address both dynamic behaviors and static correlations.

• Markov Chain Modelling: To model the dynamic transitions of drinking behaviors, a discrete-time Markov chain was implemented using the markovchain package in R. Transition probability matrices were constructed to quantify the likelihood of students moving between low, moderate, and high drinking states across academic periods. This analysis was stratified by gender and time (weekday vs. weekend) to identify key behavioral patterns.

• Statistical Analysis: Analysis of Variance (ANOVA) Test, used to test whether there were statistically significant differences in mean final grades across different levels of alcohol consumption.

• Linear regression model, a linear model fitted to estimate the precise relationship between weekend alcohol consumption (Walc) and final grades, controlling for the course type.

3. Results

The analysis revealed significant insights into the dynamics of student alcohol consumption and its tangible impact on academic performance. The findings are presented in three subsections: first, the descriptive patterns of consumption across key demographics; second, the dynamic behavioral transitions uncovered by the Markov chain model; and third, the quantified academic consequences of drinking.

3.1. Descriptive patterns of alcohol consumption

A clear dichotomy emerged between weekday and weekend drinking behaviors. Weekday consumption was overwhelmingly low across the entire cohort, with the vast majority of students reporting a drinking level of 1 in both Portuguese and mathematics courses. This pattern suggests that academic routines during the week may act as a universal suppressor of alcohol use. In stark contrast, weekend drinking exhibited greater variability and higher median values. Notably, significant gender disparities were observed. Male students demonstrated a median weekend drinking level of 3, which was substantially higher than the median of 2 for female students. Furthermore, the distribution of male drinking behaviors spanned the entire 1–5 scale, indicating a wider range of habits, from abstinence to heavy consumption. Female students' drinking levels were more concentrated at the lower end (1–3), demonstrating more consistent and moderate habits. While minor differences were noted between course disciplines, the overarching trend confirmed that low-frequency drinkers constituted the majority, with high-frequency drinkers representing a small but critical minority.

3.2. Dynamic behavioral transitions via markov chain analysis

The Markov chain analysis provided a crucial temporal perspective, moving beyond static snapshots to model how students transition between drinking states over time. The transition probability

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matrices revealed a state of persistence, particularly among male students on weekends. Those who entered a high-drinking state (level 4 or 5) demonstrated a retention probability exceeding 70%, indicating that once a pattern of heavy weekend consumption is established, it is likely to be maintained across academic periods. This finding highlights weekends as a high-risk window for the entrenchment of detrimental habits. Conversely, weekday transitions showed a high probability of students remaining in or reverting to low-consumption states, reinforcing the notion of weekdays as a "protected" period. These dynamic pathways, which were largely absent from prior static analyses, identify the specific behavioral trajectories that warrant targeted intervention.

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3.3. Quantified impact on academic performance

The statistical analyses provided rigorous, quantitative evidence of the academic cost associated with alcohol consumption. An Analysis of Variance (ANOVA) test confirmed that differing levels of alcohol consumption had a statistically significant effect on final grades (G3) across all academic periods (p-value < 0.005). To precisely quantify this relationship, a linear regression model was fitted. The model demonstrated that, after controlling for course type, each one-unit increase in a student's weekend drinking level corresponded to an average decline of 0.35 points in their final grade ($p = 0.000178$). This negative correlation was visually apparent in a scatter plot of the data, which showed a downward trend in grades as drinking levels increased. While students with low drinking levels exhibited a wide range of grades, those at the highest consumption levels (4 and 5) were disproportionately represented among the lowest academic scores, including failures. This evidence firmly establishes that increased alcohol consumption is a significant predictor of poorer academic performance.

4. Discussion

This study employed a novel Markov chain approach to move beyond static correlations and uncover the dynamic transitions in secondary school students' alcohol consumption. The results confirm a significant negative relationship between drinking and academic performance while revealing critical temporal and gendered patterns that inform a new framework for targeted intervention.

4.1. Interpretation of results

Our analysis yields two central insights. First, a pronounced gender disparity on weekends emerged as a primary risk factor. The significantly higher median drinking level and the wider behavioral range among male students, coupled with the Markov chain's revelation of high persistence (>70%) in their risky states, suggest that weekends serve as a catalyst for establishing and maintaining detrimental habits. This finding aligns with existing literature on male-dominated binge drinking patterns, but extends it by demonstrating the temporal stability of these behaviors. Second, the discovery of uniformly low weekday consumption across both genders and course disciplines is equally critical. It implies that the structure of the academic week, through its demands on time,

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routine, and cognitive load, may act as a protective barrier, effectively suppressing drinking opportunities regardless of individual or subject-specific differences

4.2. Implications for theory and practice

Theoretically, this research demonstrates the substantial value of dynamic modeling in behavioral health research. While cross-sectional studies can establish that a problem exists, our Markov chain analysis identifies when and for whom the problem is most likely to persist, offering a more nuanced understanding of behavioral pathways. Practically, these insights translate into actionable intervention strategies. Generic, school-wide anti-alcohol campaigns could be replaced with precision measures. For instance, resources should be concentrated on weekend-specific programming for high-risk groups, such as male students, including Friday awareness initiatives or Sunday support sessions designed to disrupt the transition into a new week. Furthermore, academic policy could be adjusted to avoid scheduling major deadlines on Mondays, thereby reducing the incentive for "rebound" weekend drinking as a coping mechanism for pre-week stress.

4.3. Limitations

Despite its contributions, this study is subject to several limitations. First of all, the scope of variables is constrained, potentially confounding factors such as genetic predisposition, mental health status, and detailed peer influence metrics were not available in the dataset, which may obscure a more complex causal picture. Second, the temporal resolution is limited to weekly aggregates, failing to capture day-level dynamics such as pre-exam drinking versus weekend social drinking. Finally, the data relies on self-reporting, which is susceptible to recall bias and social desirability effects, potentially leading to systematic under-reporting, particularly among female students.

Future research should aim to address these constraints through a multi-faceted approach. Measurement could be enhanced by integrating objective tools like wearable alcohol biosensors with smartphone-based Ecological Momentary Assessment (EMA) to collect high-frequency, real-time data. Modeling could evolve by developing multi-layer Markov networks that incorporate individual-level physiological data, social network matrices (e.g., via WiFi proximity logging), and institutional data (e.g., academic calendars). Finally, intervention can be transformed by using these enhanced models for real-time risk classification, triggering Just-In-Time Adaptive Interventions (JITAIs) when a student's data indicates a critical transition into a high-risk state.

5. Conclusion

This study has demonstrated that the dynamics of student alcohol consumption are as critical as its prevalence. By applying a Markov chain model to longitudinal data, we have moved beyond static correlations to map the temporal pathways of behavioral risk, revealing that when students drink and how these habits evolve are pivotal factors influencing academic outcomes.

Our analysis conclusively establishes that alcohol consumption exerts a significant negative impact on academic performance, with each unit increase in weekend drinking corresponding to a 0.35-point decline in final grades. More importantly, we identified weekends as a critical high-risk period, particularly for male students, who exhibit persistent, entrenched drinking patterns over time. Conversely, the uniformly low consumption during weekdays across all students suggests that structured academic routines can effectively act as a protective barrier against alcohol use.

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The primary contribution of this work is twofold. Methodologically, it introduces a dynamic framework for analyzing behavioral transitions, offering a more nuanced tool for educational and public health research than traditional cross-sectional approaches. Practically, it provides a data-driven foundation for precision interventions—such as targeted weekend support programs for high-risk groups and academic scheduling adjustments—that can disrupt negative behavioral cycles before they become entrenched.

In closing, this research underscores the necessity of viewing student behaviors not as static traits but as evolving processes. By understanding the dynamics of when and how risks manifest, educators and policymakers can transition from broad-stroke policies to timely, targeted actions, ultimately fostering environments that mitigate alcohol-related academic decline and promote student well-being.

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