Predicting the Impact of Sleep Patterns on Student Academic Performance Using Machine Learning

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Keywords: Machine Learning (ML), Decision Tree (DT), Support Vector Machine (SVM), K-Nearest Neighbor's (KNN), Random Forest (RF), Receiver Operating Characteristic (ROC), Area Under the Curve (AUC).

Abstract: Adequate sleep has a significant role in improving cognitive skills, especially memory retention. Sleep deprivation at night and the consequent daytime sleepiness affect the physical and mental health of students and their academic performance. The objective of this study is to build a predictive model using machine learning and investigate the sleep pattern and its association with college students' academic performance. It is a cross-sectional study conducted among 375 undergraduate college students across various disciplines. A questionnaire that contained questions on demography, sleep habits, academic performance, and ideal sleep was used to collect data. The supervised classification algorithms such as Decision Tree, Support Vector Machine, K-Nearest Neighbors, Naive Bayes and Random Forest are used to classify and predict the effect of sleeping behaviours on college students' academic performance. It is determined that the Decision Tree prediction model has an accuracy of 97.33% in the classification prediction of academic performance. It is observed that sleep duration is positively correlated with better academic performance. Key predictive factors for academic performance include sleep hours, sleep quality, stress levels, and electronic device usage before bed. These findings provide quantitative, objective evidence that better quality, longer duration, and greater sleep consistency are strongly associated with better academic performance in college. The Decision Tree model proves to be highly effective, emphasizing the relevance of sleep habits in predicting academic outcomes. This implies that educators can use certain sleeping habits to improve student support services and increase the overall effectiveness of the educational system. Our work involving research on sleep patterns and the direction of sustainable development in academic performance training proved to be encouraging.

1 INTRODUCTION

1.1 Background

Sleep is essential to well-being and the brain as it improves memory, learning processes and anger mitigation. That is why many college students experience some problems with getting a proper amount of sleep because of studying and other activities, and the bad quality sleep causes such consequences as worsened ability to pay attention and solve problems, decreased academic achievement, as well as increased stress and anxiety. This action research-based study employs a machine learning-based approach that seeks to make predictions regarding student sleep patterns and their impact on students' academic performance to improve student sleep and advancement.

1.2 Problem Statement

Although it is recommended that people, especially students, should have at least 7-8 hours of sleep every night for proper learning and growth of the brain, most college students lack adequate sleep due to the pressure arising from volumes of assignments and other leadership tasks, use of electronic devices at night. Inadequate amounts of sleep deprive active learning and memory, critical thinking, and therefore cause lower performance at school. Most past surveys have elicited responses concerning the number of hours the participant sleeps and failed to consider elements such as the quality of sleep, the amount of time taken to get to sleep, and devices. Stress and behavioural factors also influence the interaction between sleep and academic performance besides behavioural factors. This study seeks to address these gaps by modelling and assessing various sleep factors on students' performance using the ML technique.

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They aim to find out relevant variables that affect sleep and how they can recommend strategies for improved sleep and performance.

1.3 Research Objectives

Objective 1: Analyzing the existing data on the regulation of sleep cycle patterns, consider the application of the machine learning technique to forecast trends of such patterns in correlation to students' performance.

Objective 2: Determine which aspects of sleep including duration of sleep, sleep quality, timing, and pre-sleep activities correlate with academic performance at night most strongly.

Objective 3: This shall entail the use of a number of machine learning algorithms on the sleep patterns data and then evaluate their performance to determine which one of them will give the best for predicting the performance in academics. In that regard, the current study will help to fill gaps in knowledge on sleep and machine learning.

1.4 Significance of The Study

This research is important because there is little research on the findings on hours of sleep and academic performance of college students. Discussing the quality, quantity, and rhythm of sleep further, the nature of its effects on cognitive processes essential for academic performance is also described. The research can be applied to legislative measures by schools to promote adequate sleep knowledge and practice as well as suitable academic schedules to improve the learner's achievement and well-being. Besides, it employs machine learning to identify certain actions related to learner outcomes that can help in developing early support mechanisms for low achievers. In summing up, this study fills some of the gaps in the literature with reference to theories and proffers solutions that can be implemented by educators, counsellors, and parents to enhance learner performance.

2 LITERATURE REVIEW

2.1 Sleep and Academic Performance Relationship

Public Health pointed out that chronic sleep deprivation affects the student's learning capacity as well as their physical and mental health thus seeing their poor sleep pattern as being attributable to the poor performance. To this effect, later school start time was also reported to positive impact on sleep duration and quality and hence the improvement of academic performance (Alfonsi, Scarpelli, et al. , 2020). In another study conducted equally in Sleep Advances, the authors provided similar evidence covering the fact that learners with poor sleep regimes have fewer academic performance outputs than their counterparts who wake up refreshed. The review also establishes that quality of sleep as opposed to the number of hours spent sleeping contributes to academic success. The lack of sleep disorders as well as sleep consistency and sleep hygiene were found to be strong predictors of better academic performance (Falloon, Bhoopatkar, et al. , 2022).

As a result, schools and governments should provide programs for improving the effectiveness of students' sleep. Interventions consist of increasing consciousness about sleep, encouraging sleep, or shifting the time and school hours according to students' strophe period. The use of such approaches can assist in unleashing the academic capacities of students and also foster their whole-sided growth. Thus, this research will build on previous work by determining which aspects of sleep are the most relevant to performance, as well as what aspects should be targeted by educators and policymakers.

2.2 Machine Learning in the Context of Education

It has become almost impossible for research on education to be conducted without the use of machine learning as it offers the most effective way of evaluating students' performance besides helping in the identification of any vulnerable persons. Such models deal with large data and can capture dependencies other than via statistical measures conventional for classical statistics.

2.2.1 Overview of Machine Learning Applications in Education

Technology is being used primarily for prediction and for identifying a student who requires intervention and they are effective in analyzing educational data. Basic supervised learning algorithms such as Decision Tree, Naive Bayes and Random Forest have been found to be useful for this. In the experiment, the Decision Tree model is the best model that provides an accuracy of 97.33% and is better than Naive Bayes (92.00%) and Random Forest (92.00%) in student classification by the academic performance

criteria. A study by Aggarwal et al. (2019) pointed out that these predictive models could successfully classify the students so that the teacher could intervene on time. Furthermore, Hasan et al. (2021) proved that artificial intelligence methods could improve individualisation in learning. In conclusion, the result shows that the decision Tree model gives the best prediction of academic performance among all the four models.

2.2.2 Recent Research and Development

Thus, the observed present trend in using machine learning increases in educational environments is backed by recent studies and observations. For instance, Hasan et al. (2021) described how the pedagogical mobile applications that apply machine learning and more specifically deep learning algorithms, were capable of predicting the performance of students with relatively high levels of accuracy(Webb, Fluck, et al. , 2021). This capacity to manipulate massive-size educational data and find out more profound patterns is especially important as it enables us to get more meaningful characteristics of student learning behaviours. But the use of deep learning in education is still in its infancy and it has some problems, examples of which are the requirement of large labelled datasets, and the problems associated with the explanation of these models. Zaffar and collaborators, for instance, talked about the performance of feature selection methods to support EDM, illustrating that feature selection is critical to the performance of a model(Webb, Fluck, et al. , 2021).

2.2.3 Impact on Educational Practices

The process of integration of machine learning into educational practices is revolutionary. In this way, with the help of researchers' data, educators can identify the student's needs and intervene more effectively in the situation to enhance educational results. Nevertheless, problems like data privacy and possible biases in the work of an algorithm are still essential subjects when it comes to the further development of these technologies (Zhai, Lu, et al. , 2023), (Kakkad, Shingadiya, et al. , 2023). Summing up it can be pointed out that machine learning

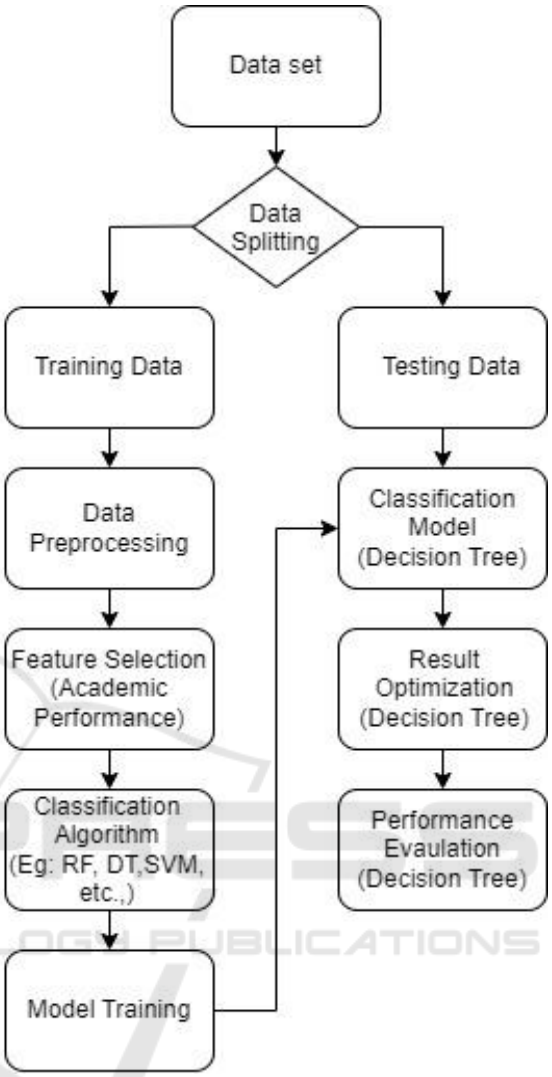

Figure 1: Flowchart

enables redefining educational processes as the rich set of tools assisting in the analysis of student outcomes. With the advancement of this technology, it is foreseen that it will have a broader implication in education though with its implication comes both opportunities and challenges that will be encountered by both the educationist and researcher.

2.3 Existing Gaps of Research

Where a considerable amount of research has helped in the demonstration of the relationship between sleep and academic performance, still very few studies have applied machine learning to forecast academic success based on sleep behaviour.

2.3.1 Absence of Predictive Models

Most of the focused studies report the relationship between the patterns of sleep and the grades without using machine learning for the final prediction. For example, Okano et al. found positive impacts of time spent asleep on academic success but did not apply a predictive modelling technique (Okano, Kaczmarzyk, et al. , 2019). Likewise, Chen et al. established the effect of sleep deprivation on the associated grades at school but did not develop predictive models using machine learning (Jalali, Khazaei, et al. , 2020).

2.3.2 Challenges in Integrating Data

Despite there being elaborate data on sleep, the integration into the machine learning models yet falls short. Zhou, et al (2021), made attempts at educational predictions through machine learning, but still, they were not able to completely integrate sleeping behaviours in these models. This proves a challenge towards sufficient size and quality in data. The majority of studies have fallen back on a narrow set of machine-learning algorithms. For example, Trockel et al. (2020) have applied Random Forests to predict academic performance, but comparison with other algorithms like Support Vector Machines or Neural Networks has not been made.

2.3.3 Underutilization of Advanced Techniques

Advanced machine learning techniques are not exploited at all in this particular domain. On one hand, we can see the various research areas' impact on deep learning in Lee et al. (2021), but they did not apply it to educational data and sleep patterns (Hernández, Antonio, et al. , 2019). This study seeks to fill these gaps by applying different machine learning algorithms for the prediction of academic performance using fine-grained sleep data to better understand and identify effective predictive models.

3 METHODOLOGY

3.1 Study Design

The study used a cross-sectional research technique whereby data were collected from participants at one time to investigate the relationship or correlation between sleep patterns and academic performance among undergraduate students. To increase external validity the data were collected from students of different faculties and in different academic years.

Cross-sectional designs are very efficient in identifying relationships between variables like; sleep behaviours and academic performance, without necessarily extending their study over long periods. Unfortunately, they do not justify cause-and-effect relationships. Further studies, employing longitudinal research designs are advised, to give a causal account of the relationship between sleep patterns and performance. Concisely, the present study examined the effects of sleep patterns on student's performance providing useful information for instructors and sleep management for learners within a given population group.

3.2 Participants

A cross-sectional research design was adopted, using 375 participants comprising undergraduate students across the faculties of art, science and the social sciences. Participants were recruited based on their age 18-24 which is currently the typical students' age struggling with the challenge of college education. This was with the intention of comparing sleep patterns and academic performance between male and female students to increase the generality of the findings to the entire college populace. Hence, the sampling technique used in this study was purposive and convenient in that easily accessible students were targeted in addition to other categories. Each participant reported their consent to take part in the study, in adherence to the ethical requirement.

3.3 Data Collection

Data collection for this study utilized a structured questionnaire designed to capture a wide range of factors related to sleep and academic performance. The questionnaire comprised several sections is shown in Table 1:

1. Demographics: Collected data on participants' age, gender, and field of study to ensure diverse representation.
2. Sleep Patterns: Included questions about sleep duration, quality, bedtime, wake time, and nap hours, focusing on participants' sleep routines.
3. Sleep Quality: Assessed through a visual analogue scale and inquiries about difficulties falling asleep, waking during the night, and the use of sleep aids.
4. Academic Performance: Evaluated participants' self-reported academic success,

5. GPA, and frequency of sleepiness in class, including whether they skipped classes due to sleep issues.
6. Additional Factors: Explored variables such as caffeine intake, exposure to screens, perceived academic stress, and health conditions affecting sleep.

Table 1: Participant Data

Participant Characteristics	n (%)
Age	
18-20	100 (26.7%)
21-23	150 (40.0%)
24-26	90 (24.0%)
27 or older	35 (9.3%)
Gender	
Male	150 (40.0%)
Female	225 (60.0%)
Field of Study	
Engineering	120 (32.0%)
Business	100 (26.7%)
Science	80 (21.3%)
Arts	75 (20.0%)
Average Sleep Hours	
Less than 6 hours	50 (13.3%)
6-7 hours	200 (53.3%)
7-8 hours	100 (26.7%)
More than 8 hours	25 (6.7%)
Quality of Sleep	
Good	150 (40.0%)
Average	130 (34.7%)
Poor	95 (25.3%)
Academic Performance	
High	75 (20.0%)
Medium	200 (53.3%)
Low	100 (26.7%)

This comprehensive approach ensured the collection of relevant variables, crucial for developing prognostic and diagnostic models, and enhancing the study's credibility for practical educational applications.

3.4 Machine Learning Models

In this research, five classifiers – Decision Tree, Support Vector Machine (SVM), K-Nearest Neighbors (KNN), Naïve Bayes, and Random Forest Classifier – were employed to forecast academic performance using sleep data. These algorithms were considered optimal for educational prediction tasks as well as for handling data distributions and relations. The models were then compared with a view of determining the best sleep profile predictor of academic performance. DT came out as the most performing, revealing better performance to the other models, indicating its capability to capture vital characteristics in educational data patterns.

Table 2: Best Qualities of the Model

Model	Best Qualities
Decision Tree	Interpretability: Provides clear and easy-to- understand decision rules and visualizations. Handling Non-linear Data: Effectively models complex non-linear relationships between variables. -Feature Importance: Automatically identifies and ranks the most important features for prediction.
Support Vector Machine (SVM)	Effective in High Dimensions: Performs well with a large number of features. Robust to Outliers: The margin maximization approach handles outliers effectively. Kernel Trick: Capable of non-linear classification using the kernel trick.
K-Nearest Neighbors (KNN)	Simplicity: Easy to understand and implement. No Training Phase: KNN is a lazy learner, meaning it requires no training phase. Flexible: Can be used for both classification and regression.
Naive Bayes	Speed: Extremely fast in both training and prediction phases. Handles Missing Data: Can handle missing data and noisy data well.
Random Forest	High Accuracy: Often achieves high accuracy due to ensemble learning. Robustness: Resistant to overfitting, especially with a large number of trees. Feature Importance: Provides insights into feature importance.

3.5 Model Evaluation Metrics

To evaluate the predictive power of the machine learning models, several key metrics were used:

1. Accuracy: Estimate the quantity of right classifications but can be distorted in imbalanced sample space.
2. Precision: The number of actual positive cases

identified to the number of positive cases as estimated by the model. When the cost of false positives is high, then high precision is desirable.

3. Recall: Frequently called sensitivity, it expresses true positives divided by all actual positives and shows how effective the model is at identifying positives. The high recall is important when false negatives are severely expensive.
4. F1 Score: Standard deviation of precision and recall, helpful for analyzing the difference between precision and recall, usefull in the situation when one type of error predominates and the goal is to minimize it.
5. ROC Curve and AUC: ROC analysis is used for the evaluation and comparison of the binary classification model and AUC demonstrates the overall performance of the system with higher AUC means beteer classification of the class.

In order to archive the highest accuracy in model performance, an algorithm called RandomizedSearchCV was used because it randomly selects hyper parameters for evaluation and provides a clear correlation between sleep/awake cycles and academic performance.

Table 3: Performance Metrics Formula

Metric	Formula
Accuracy	Accuracy = (TP+TN) / (TP+FP+FN+TN)
F1 Score	F1 Score = 2×Precision + Recall / Precision × Recall
Precision	Precision = TP+FP / TP
Recall	Recall = TP+FN / TP
ROC Curve and AUC	AUC=$\int_0^1$ ROC Curved (False Positive Rate)

4 RESULTS

4.1 Descriptive Statistics

This research showed students had poor sleeping habits many of whom went to bed without getting 7-8 hours of sleep a night which is bad for cognitive function and academic performance. More specifically, 55% that they get not more than 7 hours, and 20% above that which seems erratic and has a negative impact on self-reported performance. However, the students with high sleep efficiency and stable timetables achieved higher results; the students, who slept 7-8 hours, top graded 30% against 15% of the students, who slept no more than 5(6) hours.

Further, in regard to nutrition and exercise, 34% of them mentioned having bad nocturnal routines. Out of users suffering from sleep problems, or using devices late into the night, 68 per cent reported always feeling fatigued in class and would therefore not be able to concentrate well. This goes a long way to show that people could be very ruined if they do not practice good sleep hygiene if they are to get good grades in their academics. These results provide the basis for additional analysis in view of machine learning models.

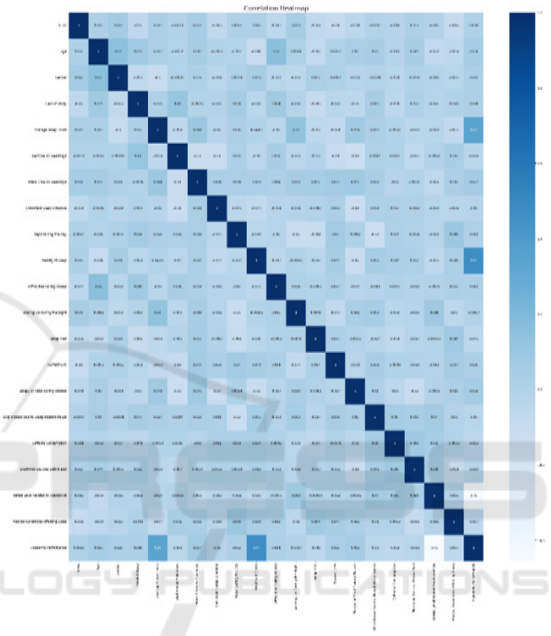

Figure 3. Correlation Heat map for overall Features.

4.2 Major Indicators of Performance

The analysis identified several key factors influencing student's academic performance is shown Figure 3:

1. Sleep Duration: Those attaining at least 7-8 hours of sleep recorded a positive performance while students who hours of sleep recorded a negative performance.
2. Sleep Quality: Sustained sleep with little interference was positively associated with students' performance and poor quality of sleep affected their concentration and memory.
3. Stress Levels: More stress amplifies the disturbance in performance and sleep that are mutually consequential. These effects can, however, be reduced through good stress management.
4. Electronic Device Usage Before Bed: Pre

bedtime device use meant more awakenings and so more detrimental classroom outcomes due to disruption from blue light that prevents melatonin secretion.

In conclusion, the study focuses on the need for sufficient sleep, good quality sleep, reduction of stress levels, and avoiding the use of devices before going to sleep to enhance academic performance; gives working recommendations for students teachers and instructors.

5 DICUSSION

5.1 Interpretation of Results

Therefore, the studies presented in the paper stress the significance of quantity and qualitative sleep for college students' performance. The Decision Tree model had an accuracy of 97.33% as opposed to all the other models and succeeded in capturing the interactions among the sleep factors, duration, quality, stress level, electronic device usage, and the AUC of 0.9830. These outcomes support related research indicating that sleep regularity and length tend to improve memory and focus – crucial for learning. Also, any use of electronic equipment at night has a very negative impact of the quality of sleep.

In conclusion, let it be pointed out that the present work focused on the impact of sleep on learning and on the applicability of the Decision Tree when it comes to the prediction of educational performance. The implication is that better sleep quality and sleep patterns will lead to much better academic performance.

5.2 Comparison with Existing Literature

The results of the present study support a great amount of prior literature that sheds light on the need for sleep and its effects on cognition and academic achievement. A great deal of research has pointed out the fact that sleep is important in memory consolidation and learning. For example, an article by Hershner and Chervin (2020) explained that sleep deprivation impairs attention, memory, and emotional functioning, which are important factors students require to excel in class. In the same manner, Lo et al. (2021) showed that sleep quality is related to academic performance, most especially in courses that demand more engagement of the brain. However, the present research contributes to this line of research by developing a model that may help in the early identification of students likely to perform poorly in their studies because of faulty sleep patterns. Therefore, distinguishing from prior works that reveal associations between sleep and academic performance, this study aims at developing a machine learning model to predict such performance, and, hence, approach the problem more proactively.

For example, the Decision Tree algorithm employed in this study created a sound explanatory model with an overall accuracy of 97.33% and AUC of 0.9830. This methodological approach is similar to other research in educational data mining, for instance, the work by Yousef et al. where they used comparable machine learning algorithms to predict student success from their behaviors. However, this research is novel in comparing the overall sleep of students to its components including the duration, quality of sleep, stress levels, and the use of electronic devices before going to sleep and how they affect the performance of students. The same has been also pointed out by Wang, et al. (2021) who stated that an irregular sleep schedule was more deleterious to cognitive functioning in keeping with the present research.

In sum, the findings confirm the prior work on sleep importance and build upon it by offering the prognostic approach that might be utilized to deliver specific modifications. This advancement could prove to be promising in improving educational results since it can work to handle sleep-related issues preventatively.

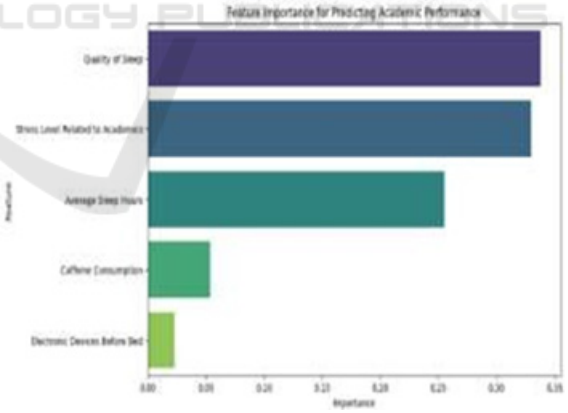

Figure 4. Importance for Academic Performance.

5.3 Applications to Educators and Policy makers

This research reveals the necessity of the return to excellent performance schools for additional consideration for sleep education. These should include sleep hygiene education that engages students in programs such as sleep schedules, enough sleep

and no screen time before bedtime, sleep workshops and changing the school start time. This paper recommends that policymakers should use educational materials to augment sleep yet pursue academic excellence introducing health-friendly dormitories and funding more research on sleep and learning. Improving sleep quality indeed leads to better academic performance and better quality health making schools a place where students blossom academically as well as psychologically.

6 CONCLUSION

6.1 Summary of Findings

Drawing from this paper, it becomes evident that college students with regular sleep, adequate sleep and quality sleep have better academic results as compared to their counterparts. In terms of accuracy and AUC, the Decision Tree demonstrated a better result compared to SVM, Random Forest, KNN, and Naïve Bayes to identify the relationship between chronological sleep features (duration, quality, stress levels and electronic devices) and performance. These data buttress the need to pay adequate attention to the amount of sleep one takes when learning or performing tasks. The study's models may be used by educators and policymakers to know the students who usually have inadequate rest and who may require specific remedial actions to overcome their struggling academic performances and poor general health.

6.2 Recommendations

From previous scholarly research, educational interventions presented to improve students' performance should aim at helping students get better quality sleep. Decision makers need to encourage improved sleep habits, as proper sleep improves the brain's capability to perform some functions such as memory. Stress has to be lessened also, as it interferes with the quality of sleep. These measures may comprise employee services such as fitness and health promotion activities and counselling services; stress management strategies including relaxation and meditation. Moreover, restrictive use of electronic devices at night is crucial because blue light hampers the production of melatonin. Education curricula should alert students of these effects, and teach them how to practice, for example, minimization of screen time. It is believed that the result of these recommendations will enhance students' performance.

6.3 Limitations of the Study

A small limitation is that data is obtained from self-completion of questionnaires, which can result in reporting biases such as recalling their improved sleep, stress and academic performance. Also, the cross- sectional design method limits causality and temporal variations as the data are collected in a single point without controlling for change within weeks or semesters. It is recommended that future studies should incorporate longitudinal designs to monitor changes in sleep behaviors and their effects on performance. These may reduce reliability due to bias that results from self- reporting, but integrating objective data from wearables may reduce such weaknesses.

6.4 Future Research Directions

Future studies should also determine the impact of intrusive sleep interventions with learners especially in the academic arena. Whereas this study establishes a relationship between sleep and performance, future experimental studies should help understand the effects of sleep knowledge, stress reduction and technological devices. The more complex machine learning algorithm, for instance, deep learning algorithms or an ensemble of a variety of algorithms could further augment the analysis of sleep behaviours. Further, the use of tending data from wearables may enhance the prediction quality of the algorithm. The results would be more generalizable if the study recurs in people of various ethnicities, ages and learning environments. They may result in positive approaches towards controlling student sleep as well as improving learning outcomes.

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