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Effect of Individual Differences in Predicting Engineering Students' Performance

A Case of Education for Sustainable Development

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Preface

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Effect of Individual Differences in Predicting Engineering Students' Performance: A Case of Education for Sustainable Development

Abstract— **The academic performance of engineering students continues to receive attention in the literature. Despite that, there is a lack of studies in the literature investigating the simultaneous relationship between students' systems thinking (ST) skills, Five-Factor Model (FFM) personality traits, proactive personality scale, academic, demographic, family background factors, and their potential impact on academic performance. Three established instruments, namely, ST skills instrument with seven dimensions, FFM traits with five dimensions, and proactive personality with one dimension, along with a demographic survey, have been administrated for data collection. A cross-sectional web-based study applying Qualtrics has been developed to gather data from engineering students. To demonstrate the prediction power of the ST skills, FFM traits, proactive personality, academic, demographics, and family background factors on the academic performance of engineering students, two unsupervised learning algorithms applied. The study results identify that these unsupervised algorithms succeeded to cluster engineering students' performance regarding primary skills and characteristics. In other words, the variables used in this study are able to predict the academic performance of engineering students. This study also has provided significant implications and contributions to engineering education and education sustainable development bodies of knowledge. First, the study presents a better perception of engineering students' academic performance. The aim is to assist educators, teachers, mentors, college authorities, and other involved parties to discover students' individual differences for a more efficient education and guidance environment. Second, by a closer examination at the level of systemic thinking and its connection with FFM traits, proactive personality, academic, and demographic characteristics, understanding engineering students' skillset would be assisted better in the domain of sustainable education.**

I. Introduction

Education literature has emphasized the significance of the academic performance of college students, with the main focus on students majoring in engineering fields. A deep search in education literature has prevailed various factors that may impact the proficiency of students' performance in academics. These factors belong to six various domains of personality traits, psychosocial contextual influences, motivational factors, students' approaches to learning, and self-regulatory learning strategies [1-8]. Education literature has provided a precise look into the different instruments and measures that were developed and utilized for many years. However, the simultaneous effect of three possible predictors, namely, Systems Thinking (ST) skills in the domain of complex systems, proactive personality, and Five-Factor Model (FFM) traits, are not examined sufficiently in both complex system areas and engineering education literature. Studies have shown that systems thinking is associated with personality types utilizing the Myers-Briggs Type Indicator (MBTI) instrument [9-14]. Furthermore, both FFM traits and proactive personality can be associated with many dimensions of ST skills such as Interaction, Autonomy, Change, Complexity, Hierarchical View, and Flexibility dimensions. With this being said, the goal of the current study is to apply FFM traits, proactive personality, and ST skills measures to study the correlation between engineering students' academic performance and the mentioned skills and characteristics. The importance of considering the various factors influencing students' academic performance lies in the students' future participation in the workforce. Forming students that will fulfill the missing requirements of various industries and sectors, such as healthcare, military, and others, is crucial. Thus, it is relevant to determine all potential characteristics that can influence and improve students' academic performance. Since existing literature lacks studies investigating the correlation between ST skills, FFM traits, and proactive personality with the academic performance of engineering students across gender, these three skills and characteristics are considered as possible factors for the current study. The aim of this study is to fill the gap present in literature by proposing a thorough analysis that evaluates the impact of the provided factors, which are ST skills, FFM traits, and proactive personality, academic factors, demographics, and family background indicators on engineering students' academic performance considering the moderation effect of gender. In the following section, a brief overview of the literature is presented, which is followed by the methodology, results, and conclusion.

II. Background of Study

Students' Academic Performance: A detailed look into education literature prevailed that many non-intellective factors affect students' academic performance. To comprehend the nature of these factors, six different themes have been analyzed based on the body of knowledge already existent in the literature. The different domains consist of personality traits, motivational factors, self-regulatory learning strategies, students' approaches to learning, and contextual psychology. As an instance, Poropat [2] indicated that students' academic performance is influenced by several personality characteristics such as openness, agreeableness, and others. The purpose of this study is to investigate the factors affecting students' academic performance.

Systems Thinking (ST) in Education: System thinking skills are being used to navigate complex systems, as complex systems problems are characterized by their overall complexity, uncertainty, vagueness, and other characteristics that hinder their handling [15-17]. These complex problems' characteristics need particular knowledge, containing nontechnological, inherently social, organizational, and political knowledge for minimizing the complexity of the problems [15-17]. After an extensive search of the literature, ST was found to be the most used method to deal with complex systems. ST gives individuals the capability to think of a given complex system in a holistic manner. This ability grows the system's understanding and helps to decrease the level of system complexity. As this study focuses on the relationship between ST skills and academic performance, in particular, reviewing the current literature showed that ST is widely applied in literature as there are several studies that utilize ST in education [18-24]. For example, in a study conducted by Bloom [18], a system taxonomy is developed to study students' critical thinking in the classroom. Six levels were included in Bloom's taxonomy, which required its own body of knowledge. The purpose of Bloom's taxonomy was to increase students' critical thinking and grow their reasoning ability. In another stream of research, students' system thinking capabilities were assessed by developing an inventory, including several set of tasks that measures targeted system thinking skills (Sweeny and Sterman [19]). In another study, Scherer & Tiemann [20] studied the impact of both task interactivity and grade level on problem-solving skills. They tested 805 high-school students on multidimensional constructs to investigate the necessary thinking skills for problem-solving. In the hopes of studying factors influencing the development of ST skills among students, Assaraf and Orion [21] investigated high school level students' abilities in dealing with complex systems, and both qualitative and quantitative approaches were employed to manage thestudy. To improve the education system as a complex system, system thinking skills are required [22]. The system thinking teaching application was noticed between the years 1980 and 2000, where different countries started enhancing students' system thinking skills [23]. Several studies examined the impact of students' system thinking skills on their academic performance. As an example, the relationship between higher-order system thinking skills and students' academic performance in mathematics subjects was studied by Tanujaya et al. [24]. As a consequence, Tanujaya et al. [24] inferred the existence of a strong correlation between those two variables. There is an increasing emphasis on system thinking in education nowadays, due to people noticing the value of system thinking in education.

Five-Factor Model (FFM) personality traits: Taking that into account, the meaning of personality and its description has been in the focus of researchers. The significance of personality has been emphasized over the past decade as researchers have been focused on narrowing personality trait descriptors to come up with the "Big-Five" [25]. With the research being performed extensively concerning the Big-Five, a newer univocal set of factors markers was introduced by Goldberg. The Big-five feature set includes the Surgency, Agreeableness, Conscientiousness, Emotional Stability, Intellect [26]. These introduced features can also be applied as an alternative for the scale for personality inventories approaches. Students' academic performance has been a concern for many years, as many attempts have been made by researchers to find the features which affect academic performance. Considering these features, studies have indicated the linkage between the big five personality characteristics and students' academic performance [27]. For instance, Vedel [27] applied a meta-analysis to examine the relationship between the big five personality traits and students' academic performance and concluded that Conscientiousness, one of the big five personality traits, has a significant correlation with students' GPA. Researchers use GPA frequently and consider it as a fundamental measure of students' academic performance [28]. Zeindner and Matthews [29] indicated that as openness trait helps students in creating new methods of learning, it developed academic performance. Moreover, studies have assessed the linkage between academic procrastination and personality traits. Kim et al. [30] inferred that three of the big five personality traits have a negative correlation with passive procrastination, such as extraversion, agreeableness, and Conscientiousness. Furthermore, Kim et al. [30] suggested that Neuroticism has a correlation with both active and passive procrastination. To an extent, the current study shows that the five big personality traits all have correlations in different ways with procrastination. In another study, the influence of both the Big-Five traits and self-efficacy on students' academic performance was investigated by Stajkovic et al. [31]. Poropat [2] indicated that personality is an essential feature in academic performance and should be considered in future theories.

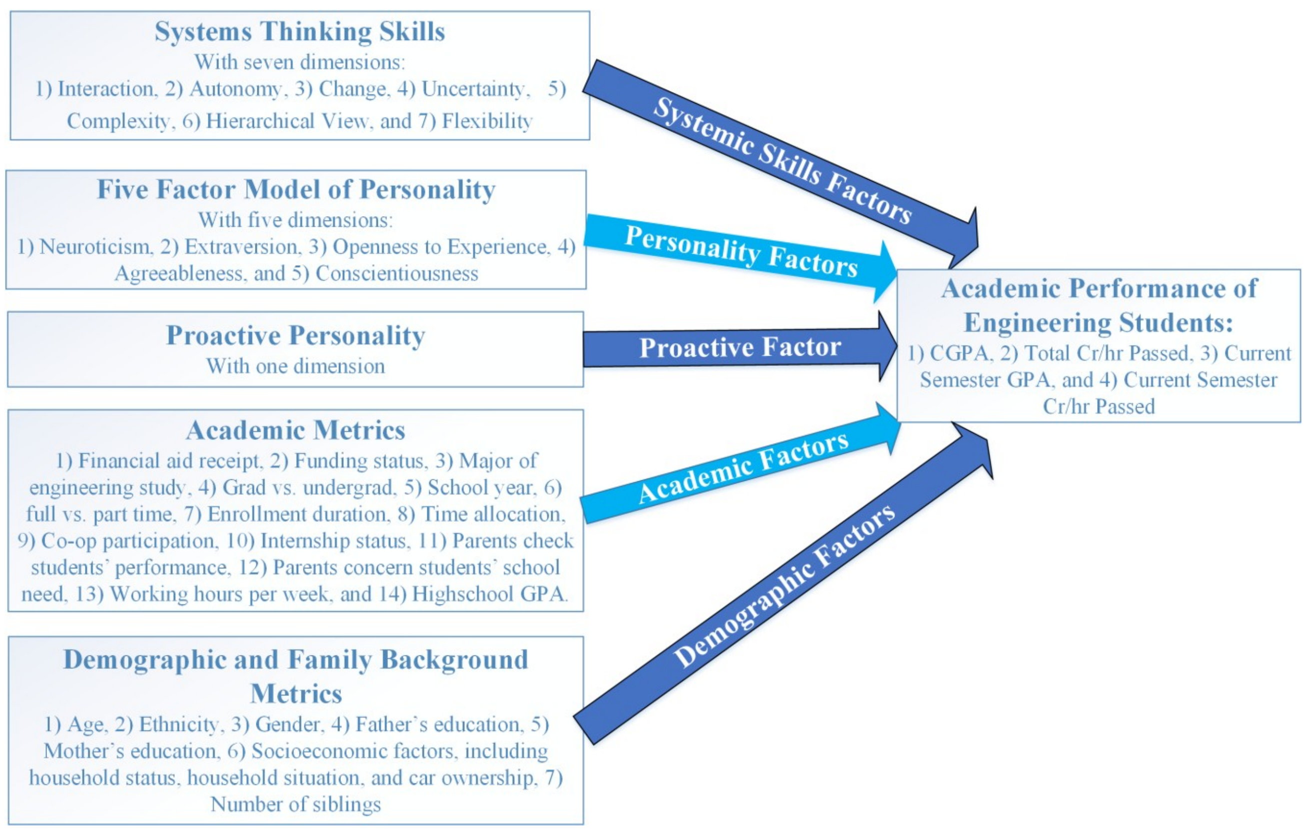
Proactive Personality: Proactive personality first appeared in a study done by Bateman and Crant [32]. The authors defined proactive personality as the scale by which an individual influences his environment, as expanded in the later studies [33,34]. The correlation between both proactive personality and education has not appeared in the education literature; while, studies have shown the impact of several psychological features such as personality on college students' abilities. In a study conducted by Prayoonsri et al. [35], a direct link has been established between classroom environment, psychological characteristics, intellectual characteristics, and family characteristics and the higher-order thinking of students. The psychological characteristics mentioned in the study contain personality traits that affect an individual's thought process. Prayoonsri et al. [35] has created a systematic model that integrates the various features and applies a meta-analytic structural equation modeling (MASEM) to do the analysis. Due to the lack of studies investigating the impact of proactive personality on the students' academic performance, another goal of the current study is to fill the current gap present in literature by examining the influence of proactive personality on students' academic performance.

III. Methodology

The descriptive statistics for the sample of the population is presented, followed by instruments and variables used in the study and then the description of the features dataset. Students' skills and characteristics with their academic performance. Then, unsupervised learning is employed to investigate the impact of engineering students' skills and characteristics on their academic performance measures. Fig. 1 depicts the theoretical framework of the study.

Descriptive statistics: Engineering students in a public large southern US university were surveyed. Respondents were informed that their participation was entirely voluntary and anonymous. The percentage ratio of male respondents was 48%. 46% of the students were graduate students. About 90% of students were full time. Nine percent of engineering

FIG. 1. THE THEORETICAL FRAMEWORK OF THE STUDY.



students were junior, 45% of students were senior, 15% of them enrolled in a master's degree, and 31% doctoral students. The average age of respondents was 25.9 years, with an *SD* of 6.4 years.

Instruments: We employed three confirmed instruments, namely 1) 39-questions ST skills instrument with seven dimensions as shown in Table I (a=0.92) [15-17], 2) 120-questions version of Five-Factor Model (FFM) personality traits instrument, called the IPIP-NEO-120 [42] with five dimensions (a=0.87), and 3) 7-questions proactive personality instrument with one dimension (a=0.88) [32,33] were administrated for data collection. According to the grounded theory coding method, the System Thinking instrument was developed utilizing mixed quantitative and qualitative research approaches [15-17]. All of the related scale development analyses were conducted to assure the instrument's construct validity. Table II presents the main dimensions, sub-dimensions, and item descriptions of the FFM personality traits instrument [42]. All the questions were close-ended.

TABLE I: SEVEN DIMENSIONS OF SYSTEMS THINKING (ST) SKILLS INSTRUMENT [15]

Dimension	Description
Level of Complexity:	Comfort with multidimensional problems and limited system understanding.
Level of Autonomy:	Balance between local-level autonomy versus system integration.
Level of Interaction:	Interconnectedness in coordination and communication among multiple systems.
Level of Change:	Comfort with rapidly shifting systems and situations.
Level of Uncertainty:	Acceptance of unpredictable situations with limited control.
Level of Hierarchical View:	Understanding system behavior at the whole versus part level.
Level of Flexibility:	Accommodation of change or modifications in systems or approaches.

Features Dataset: Table III indicates all the features and measures have been used to cluster engineering students. These features and variables were utilized as input/independent variables of the study. According to the literature [1-41, 55], these measures and features are important indicators of students' academic performance.

IV. RESULT

In this study, two clustering methods, namely KMeans and Birch, are employed to demonstrate the relationship between engineering students' skills and characteristics with their academic performance, including recently completed semester (called SGPA) and cumulative GPA (CGPA) as well as Total Credits/hours Passed (TCP) and current Semester Credits/hours Passed (SCP). In this study, CGPA, SGPA, TCP, and SCP were considered as indicators of engineering students' academic performance, which is common in the literature [1-7].

Scikit-Learn library in python was used for the unsupervised machine learning part of the hypothesis as well as data preprocessing, the dimension reduction, hyper-parameters tuning, and clustering metrics.

After preprocessing the data, we transformed the data into new coordinates with PCA. Then we utilized two clustering techniques, namely KMeans and Birch, to cluster the engineering students based on their system thinking skills scores, personality traits, proactive personality, academic, demographics, and family background factors. GridSearchCV

TABLE II. THE FIVE DIMENSIONS, SUB-DIMENSIONS, AND ITEM DESCRIPTIONS OF THE FFM PERSONALITY TRAITS INSTRUMENT [42].

Main Dimensions	**Sub-dimensions**	**Item Description Example**
Neuroticism	1. Anxiety	e.g., Get stressed out easily
	2. Anger	e.g., Lose my temper;
	3. Depression	e.g., Often feel blue
	4. Self-Consciousness	e.g., Comfortable with friends
	5. Immoderation	e.g., Go on binges
	6. Vulnerability	e.g., Feel that I'm unable to deal with things
Extraversion	1. Friendliness	e.g., Keep distance
	2. Gregariousness	e.g., Love large parties
	3. Assertiveness	e.g., Try to lead others
	4. Activity level	e.g., Do a lot in my spare time
	5. Excitement	e.g., Seek adventure
	6. Cheerfulness	e.g., Look at the bright side of life
Openness to Experience	1. Imagination	e.g., Have a vivid imagination
	2. Artistic interest	e.g., Believe in importance of art
	3. Emotionality	e.g., Feel others' emotions
	4. Adventurousness	e.g., Prefer variety to routine
	5. Intellect	e.g., Love to read challenging material
	6. Liberalism	e.g., Tend to vote for liberal candidates
Agreeableness	1. Trust	e.g., Trust others
	2. Morality	e.g., Take advantage of others
	3. Altruism	e.g., Love to help others
	4. Cooperation	e.g., Love a good fight
	5. Modesty	e.g., Have a high opinion of myself
	6. Sympathy	e.g., Sympathize with the homeless
Conscientiousness	1. Self-Efficacy	e.g., Complete tasks successfully
	2. Orderliness	e.g., Like to tidy up
	3. Dutifulness	e.g., Keep my promises
	4. Achievement	e.g., Work hard
	5. Self-Discipline	e.g., Am always prepared
	6. Cautiousness	e.g., Jump into things without thinking

was employed to tune the hyper-parameters of both clustering algorithms with 10-folds cross-validation sorting by the Sillhouette score.

BIRCH (Balanced Iterative Reducing and Clustering using Hierarchies) utilized tree data structure consists of nodes with each node consisting of some subclusters. The branching factor determines the maximum number of subclusters in a node.

KMeans clusters the data by separating samples in K groups of equal variance, minimizing a criterion known as the sum of squares within-cluster.

Evaluating the clustering algorithm's performance is more challenging than a supervised classification algorithm, especially when we do not have the actual label for each instance. Subsequently, the Silhouette score is employed to measure the above clustering goodness. The Silhouette score for a sample is (b - a) / max(a, b) where (a) is the mean intra-cluster distance and (b) is the mean nearest-cluster distance for that sample. After clustering as an unsupervised learning method, two post-hoc tests have been performed to validate the results. Table IV shows the results of between-groups ANOVA across three clusters of engineering students. Table V presents the results of the Tukey HSD t-test across three identified clusters. Both results indicate that the clustering method succeeded in classifying students based on their academic performance.

TABLE IV. BETWEEN-GROUPS ANOVA ACROSS THREE CLUSTERS OF ENGINEERING STUDENTS

Performance metrics	Between-Groups ANOVA	
	F	Sig.
CGPA	6.233	.003
Total Cr/hr Passed (TCP)	11.747	.000
Current Semester GPA (SGPA)	2.808	.067
Current Semester Cr/hr Passed (SCP)	6.123	.004

V. CONCLUSION

This study investigates how engineering students' skills and characteristics influence their academic performance. To show the prediction power of different impacting factors, including systems thinking skills, FFM personality, proactive personality, academic factors, demographic and family background factors on the academic performance of engineering students, two clustering methods Birtch and K-means, have been utilized.

The study findings found that systems thinking skills, personality traits, proactive personality, academic indicators, demographics, and family background factors are important predictors of engineering students' academic performance.

According to the literature [1-7], there exist five different domains that influence students' academic performance, and all selected factors of the current study, namely personality traits, proactive personality, systems thinking skills, academic indicators, demographics, and family background factors, belong to the most important domains. Additionally, it is common to select a few correlated factors from some of the five domains [1-7], which is similar to the current study approach. Past research showed that systems thinking is correlated with personality traits [9-14]. In addition, FFM traits and proactive personality can be correlated to several dimensions of systems thinking skills such as level of Interaction, Autonomy, Complexity, Change, Uncertainty, Hierarchical View, and Flexibility. Thus, the FFM traits, proactive personality scale, and systems thinking skills measure are utilized to investigate if there is a relationship between these indicators and engineering students' academic performance. Since the study is a pilot testing of a larger study, future research will shed more light on the validity and reliability of the current study findings. Future research will concentrate on rectifying the limitations of the current study.

TABLE III. FEATURES AND MEASURES COLLECTED FROM ENGINEERING STUDENTS.

Measures	Dimension/Category		Description
System Thinking Skills	*Interaction*		39 binary accuracy questions to measure level of systems thinking skills of engineering students pertaining to seven dimensions.
	Autonomy		
	Change		
	Uncertainty		
	Complexity		
	Hierarchical View		
	Flexibility		
Five Factor Model of Personality	*Neuroticism*		120 five-Likert scale questions to assess personality traits of engineering students pertaining to 5 main dimensions and also 36 subdimensions, as introduced in Table II.
	Extraversion		
	Openness to Experience		
	Agreeableness		
	Conscientiousness		
Proactive Personality	*1. I am constantly on the lookout for new ways to improve my life.* *2. Wherever I have been, I have been a powerful force for constructive change.* *...* *17. If I see someone in trouble, I help out in any way I can.*		17 seven-Likert scale questions to measure the level of proactive personality of engineering students.
Academic Factors	Did you receive any student financial aid, or did you take out a student loan to help pay for your school?		15 questions to gather information related to academic factors of engineering students.
	How do you divide your funding sources to pay school tuition and living expenses? Indicate your answer by assigning a percentage of funding to each category.	Grant	
		Loan	
		Scholarship	
		Self/family fund	
		Your job income	
	What is your major of Engineering study?		
	Graduate or undergraduate		
	What year of school are you currently enrolled in?		
	Are you a full time or part time student?		
	How long have you been in your current degree program?		
	How do you divide your time on a typical weekday?	Academics (e.g. attending class, completing schoolwork)	
		Extracurricular activities (e.g. campus organizations, church events)	
		Work (part time or full-time job on or off campus)	
		Social (0n-academic activities with friends)	
		Family (0n-academic activities with family)	
		Life Activities (e.g. sleep, eat, personal hygiene)	
	Have you completed a co-op in your discipline?		
	Have you completed a professional internship in your discipline?		
	Are you currently employed (whilst being a full-time student, 0t including co-op/internship)?		
	How many hours per week do you work, approximately?		
	What was your high school cumulative GPA, approximately?		
	How often does your parent(s) check in with you concerning your performance at school?		
	How often does your parent(s) check in with you concerning your needs related to schooling?		
Demographic and Family Background Factors	*What is your gender?*		9 questions related to demographics and family background of engineering students.
	What is your ethnicity/race?		
	How old are you?		
	How far in school did your father or male guardian go?		
	How far in school did your mother or female guardian go?		
	Which of the following best describes the household in which you grew up?		
	How many siblings did you live with while growing up? Please include any siblings (including half- and stepsiblings) that lived in the same household as you a majority of the time.		
	Which of the following best describes your parents' household situation? (If they have a mortgage, select ' they own it')		
	Do you own a private car or van?		

TABLE V. POST-HOC TUKEY HSD T-TEST TO COMPARE THE PERFORMANCE METRICS OF ENGINEERING STUDENTS

Performance Metrics	Cluster (I)	Cluster (J)	Mean Difference (I-J)	Std. Error	Sig.
CGPA	1	2	.361*	.112	.005
		3	.273*	.108	.037
	2	1	-.361*	.112	.005
		3	-.088	.124	.758
	3	1	-.273*	.108	.037
		2	.088	.124	.758
Total Cr/hr Passed	1	2	-29.25*	11.55	.036
		3	-53.40*	11.19	.000
	2	1	29.25*	11.55	.036
		3	-24.15	12.84	.152
	3	1	53.40*	11.19	.000
		2	24.15	12.84	.152
Current Semester GPA	1	2	.515	.228	.069
		3	.029	.221	.991
	2	1	-.515	.228	.069
		3	-.486	.254	.142
	3	1	-.029	.221	.991
		2	.486	.254	.142
Current Semester Cr/hr Passed	1	2	-1.96	1.13	.199
		3	-3.79*	1.09	.003
	2	1	1.96	1.13	.199
		3	-1.82	1.25	.318
	3	1	3.79*	1.09	.003
		2	1.82	1.25	.318

The study concludes that:

- Systems thinking skills, FFM traits, proactive personality, academic factors, demographics, and family background factors are important predictors of engineering students' academic performance.
- Seven systems thinking dimensions have a significant impact on engineering students' academic performance since the level of systems thinking skills differ across the identified clusters.
- Five personality traits of the FFM instrument and proactive personality have a significant impact on engineering students' academic performance because of differences in these measures across the clusters of students.
- Academic indicators, demographic, and family background factors are predictors of students' performance, and these factors vary across three clusters.
- Both clustering methods, namely KMeans and Birch, yield consistent and similar results that show the validity and promising of results.

The relatively small sample size is one of the study limitations; however, it is normal due to the pilot nature of our study. To validate the current results, more efforts should be made to gather a larger sample of engineering students. Although it is recommended that a large sample size produces robust and valid results, research also shows that small sample size data can produce meaningful findings [43-45]. Future studies can concentrate on how other factors, such as motivation, self-efficacy, and proactive behavior in conjunction with current study variables, might affect the performance of engineering students. All the mentioned measures and scales, including motivation, self-efficacy, proactive behavior, as well as the current study variables are part of the comprehensive theoretical model of a bigger study, which will be applied for future data collection and analysis. Other analytical models, such as optimal control and object-oriented modeling, mathematical modeling [46-54], can be used in conjunction with clustering to better interpret the results in later studies. Future studies would also include the type of training needed to enhance students' level of characteristics and skillset to obtain better academic performance.

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14. ABSTRACT

The academic performance of engineering students continues to receive attention in the literature. Despite that, there is a lack of studies in the literature investigating the simultaneous relationship between students' systems thinking (ST) skills, Five-Factor Model (FFM) personality traits, proactive personality scale, academic, demographic, family background factors, and their potential impact on academic performance. Three established instruments, namely, ST skills instrument with seven dimensions, FFM traits with five dimensions, and proactive personality with one dimension, along with a demographic survey, have been administrated for data collection. A cross-sectional web-based study applying Qualtrics has been developed to gather data from engineering students. To demonstrate the prediction power of the ST skills, FFM traits, proactive personality, academic, demographics, and family background factors on the academic performance of engineering students, two unsupervised learning algorithms applied. The study results identify that these unsupervised algorithms succeeded to cluster engineering students' performance regarding primary skills and characteristics. In other words, the variables used in this study are able to predict the academic performance of engineering students. This study also has provided significant implications and contributions to engineering education and education sustainable development bodies of knowledge. First, the study presents a better perception of engineering students' academic performance. The aim is to assist educators, teachers, mentors, college authorities, and other involved parties to discover students' individual differences for a more efficient education and guidance environment. Second, by a closer examination at the level of systemic thinking and its connection with FFM traits, proactive personality, academic, and demographic characteristics, understanding engineering students' skillset would be assisted better in the domain of sustainable education.

15. SUBJECT TERMS

Engineering education, sustainable development, engineering students, academic performance, Systems thinking skills, big five personality, proactive personality, individual differences, unsupervised learning

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