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Determining student progression rates using discrete-time Markov chain model

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ABSTRACT

This study aims to analyze and understand the student progression from the Bachelor of Science in Mathematics (BS Math) program. A discrete-time Markov chain (DTMC) model was used to analyze data from 211 students enrolled from 2011-2012 to 2022-2023. The results reveal that there are students who will be retained in their year level, shift to another degree program, or drop. Additionally, the highest risk of shifting or dropping out of the program happens during the first two semesters in college or for first year in college. A bottleneck effect during the second year and third year was identified. Furthermore, the results suggest that there will be an approximately 35.22% graduation rate after eight semesters or four years, implying a large portion of BS Math students will be retained or dropped from the program, or shifted to other degree programs. To avoid such, it is suggested that the Mathematics and Natural Sciences Department should conduct review sessions, bridging programs, and continuous promotion. Lastly, it is suggested to conduct thorough studies about the possible intrinsic and extrinsic factors affecting the student progression to formulate a more specific intervention that may help in reducing the shifting and dropping rate.

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1. INTRODUCTION

A college degree is a noteworthy achievement that can have a transformative impact on individuals and society. Even though the skepticism about the value of earning a college degree increases in time, it is still a sound investment and the best avenue to acquire knowledge and communicate effectively leading to improving oneself [1]. However, the value of a college degree is not just academic; it also has economic implications, with college graduates typically earning more over their lifetimes [2]. In addition, the value of education increases in dynamic economic environments, with general education becoming more important in adapting to fast-paced changing conditions due to the advancement of information and technology [3]. Regardless of the academic and economic benefits of having a college degree, access to higher education remains a challenge, particularly for adult learners especially those with multiple responsibilities and financially challenged [4], [5]. The timely completion or finishing the college degree is affected by various factors such as proximity, mobility or place of residence [6], and cognitive ability which includes academic assessment related to the past and current academic performance of students [7]–[9]. Recent papers suggest that procrastination, which is caused by difficulty of the course or degree program [10], and unit overload may negatively affect the timely completion of a college degree program [11]. Family and work commitments and time management challenges are also significant predictors of college completion [12]. These problems can be observed everywhere and must be addressed properly.

In the Philippines, a typical college student takes four or five years to finish a college degree program. Nevertheless, Filipino college students face a range of challenges and predicaments that can hinder their completion of college degrees. Additionally, some students chose to drop out of their program. Academic stress, including pressure from their teachers and peers, is a significant issue [13]. Some students from indigenous communities such as "Aetas", struggle with language barriers, cultural differences, and low self-esteem [14]. One of the Philippine government's initiatives is the tertiary education subsidy (TES) program, part of R.A. 10931 also known as the "universal access to quality tertiary education act", aims to support those students that are impoverished yet deserving students [15]. However, concerns about the long-term financial viability persist, and there are shortcomings in the implementation particularly the delayed fund allocation [16]. Hence, every academic institution must conduct proactive measures in detecting the students who take longer to finish their program and those who drop out to support struggling students and improve retention rates [17]–[19]. These identified dilemmas emphasize the need for targeted support and interventions to help Filipino students succeed in college.

One of the programs offered at Pangasinan State University–Urdaneta City Campus (PSU Urdaneta) is the Bachelor of Science in Mathematics (BS Math). The BS Math program has possible specializations in pure mathematics, statistics, and computer information technology under the supervision of the Mathematics and Natural Sciences Department of the College of Computing. Of course, the BS Math program is not exempted from the dilemma of completing the degree beyond the regular number of years. It was observed in the study of Ahmad *et al.* [20] which also aligns on the report from the Office of the Campus Registrar of PSU Urdaneta, that there have been a large number of undergraduate mathematics or BS Math students who failed to finish the program because of the following reasons: i) they shifted to another program offered within the university (BS Math student who will transfer to a board program); ii) transferred to another academic institution; and iii) dropped from the BS Math program due to various reasons. Thus, there is a need to study the student progression of the BS Math program as a basis for strategic planning to prevent the shifting, dropping, and delay of the students.

Markov chain analysis has been utilized by many researchers to analyze the students' progress in higher educational institutions. Markov model was used to evaluate the academic performance of students in a four-year engineering program in an institution located in India [21]. Markov chain was employed in Eledum and Idriss [22], to calculate the probabilities of students' progression between successive semesters of the study program for each academic year. Another study employed Markov model to estimate the probability of students in different levels for graduating without delaying, the probability of academic dismissal and dropping out of the system before attaining the maximum qualification over the batches [23]. The expected time that a student spends at particular stage as well as the expected duration of the study is determined using Markov chain [24]. In addition, the Markov chain model was used to define an index estimating university dropout risk, showing the highest dropout probability in first two semesters (or first year of college) [25]. Lastly, a study by Tedeschi *et al*. [26] shows that Markov chain can improve models for estimating student retention and graduation rates by increasing confidence and reducing the estimation biases especially for underrepresented students or cases with small sample sizes.

This study aims to analyze the student progression of the program that can help the Department of Mathematics and Natural Sciences of the College of Computing develop a plan to reduce the number of students who are delayed and drop out. This study uses the discrete-time Markov chain (DTMC) model to analyze the performance of BS Math students, determine the average number of semesters it takes for BS Math students to complete the program and the likelihood of students dropping out of the program or advancing from their last semester. The application of DTMC in analyzing student progression introduces a stochastic or probabilistic approach to understanding how BS Math students traverse from one state to another using the PSU Urdaneta data. Unlike common deterministic models, the DTMC model captures the latent uncertainties and variability in student progression by treating their progression as states with probabilistic transitions. Aside from contributing to the scarce reference on the applications of DTMC in the Philippine education setting, this methodology enables a data-driven forecast of future academic outcomes, helping the administrators and faculty members identify students who are at-risk and optimize intervention strategies for the BS Math program. The novelty lies in the incorporation of real-world scholastic record data with probabilistic modeling, allowing a more dynamic insight compared to conventional statistical methodologies.

2. METHOD

A request letter noted by the campus executive director was sent to the office of the campus registrar. The requested data set is the complete enrollment data from the BS Math program starting from academic year (A.Y.) 2000-2001 to 2022-2023 which includes the students' entry (enrollment) every semester in the BS Math program and their exit (either graduated, shifted or dropped) in the program. After data cleaning and verification, the students who were enrolled in the BS Math program from A.Y. 2000-2001 to 2010-2011 were removed due to incomplete information. A total of 211 students enrolled from A.Y. 2011-2012 to 2022-2023 were kept for this study.

2.1. Software specification

RStudio was used to apply Markov chain analysis in the final data set. It is an integrated development environment (IDE) for R that includes a console, and syntax, highlighting editor that supports direct code execution, and tools for plotting, history, statistical analyses, debugging, and workspace management. Moreover, the Python editor in Notepad++ was used to generate a more decent transition matrix plot.

2.2. Discrete-time Markov chain analysis

The exploration of the theory and applications of the DTMC is evident in various fields of study. DTMC is used in analyzing and predicting time series [27]–[29], demonstrating their effectiveness in the context of this study. Aside from the theory of DTMC, its applications can be extended to discrete-time two-time-scale Markov chains, including their use in filtering, estimation, control, optimization, and financial engineering [30]. Overall, DTMC can be used to describe the behavior of any system that traverses from one state to another state with a determined probability, and this probability of transition to the next state is dependent only on the current state of the system. This also means that the probability of transition is not dependent on which state the system was in before the current state.

In this study, semesters (1st and 2nd) per year level (1st year to 4th year), graduated, shifted, and dropped are the states. the movement of the system starts in the first-year, first semester and will move to another state until it reaches either the graduated state, shifted state, or dropped state. Thus, the semester every year level is the transition state, the graduated, shifted, and dropped are the absorbing states. The system allows the movement from the current state to the previous state indicating the status of a student may return to the previous year level if she/he fails to pass her/his core mathematics subjects in the current state. Furthermore, the following conditions are assumed: i) the system applies to all BS Math students; ii) the probabilities of moving from one state to all other states are equal to one; and iii) the probabilities are constant in the long run. This system can be explained further through a mathematical model in the succeeding discussions.

Consider a finite discrete time homogeneous sequence $\{X_n : n \in \mathbb{Z}^{nonneg}\}$ of random variables. In this case, X_n indicates the current state of the process at a time n. A set containing all states is called the state space S, thus, $X_n \in S$. Moreover, the stochastic process here satisfies the memoryless of the stochastic process or the Markov property, that is, given the present semester and year level of a student, the next step is independent of the prior semesters and year levels of the current state. Now, for $i, j, x_0, x_1, \cdots, x_{n-1} \in S$.

$$P(X_{n+1} = j \mid X_0 = x_0, X_1 = x_1, \cdots, X_{n-1} = x_{n-1}, X_n = i) = P(X_{n+1} = j | X_n = i) = P_{ij}$$

Where, P_{ij} is the probability of moving from state i to another state j in just one transition and all these quantities define the matrix of one-step transition probabilities P, that is,

$$P = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1k} \\ p_{21} & p_{22} & \cdots & p_{2k} \\ \vdots & \vdots & \ddots & \vdots \\ p_{k1} & p_{k2} & \cdots & p_{kk} \end{bmatrix}$$

Where, the finite set $\{1,2,\cdots,k\}$ is the state space of the Markov chain. Each entry P must satisfy the conditions. This matrix is called the transition matrix P. The recurrent state i is called the absorbing state if $P_{ii} = 1$. The transition matrix can be written in its canonical form. The canonical form is just a partitioned transition matrix into four matrices. Thus, the canonical form of the transition matrix P of the system of this study is:

$$P = \begin{pmatrix} Q & R \\ 0 & I \end{pmatrix}$$

Where, I is an 3×3 identity matrix that corresponds to three absorbing states, 0 is a 3×8 zero matrix, Q is an 8×8 matrix of transition probabilities for the transient states, and R is an 8×3 matrix of transition probabilities for the absorbing states. In general, the transition matrix is a square matrix that describes the probability of moving from one to another within the system and can be used to extend this concept into longer time intervals.

Another important concept related to DTMC is the fundamental matrix. The fundamental matrix N of a Markov chain is a matrix that gives information regarding the expected number of times a process is in each state, given that the system starts in a particular state. Mathematically, each entry of the matrix N, say n_{ij}, can be thought of as the expected number of times the chain is in j if it started in i. Moreover, the fundamental matrix N can be defined as $(I_{z\times z} - Q_{z\times z})^{-1}$, where it is known that $I_{z\times z} - Q_{z\times z}$ is an invertible matrix. Another important quantity is the probability U_{ij}. This value represents the probability of moving from a transient state i to an absorption state j. If the matrix U contains each U_{ij}, then $U = NR$ [31]–[33].

3. RESULTS AND DISCUSSION

Table 1 shows the values for the transition probability matrix which are interpreted as the probabilities of a student's progression from one semester to the next semester. As shown in the table, the top three highest probability of progression are from second-year first semester to second-year, second semester with 95.91%, from third-year first semester to third-year second semester with 95.11%, and from first-year second semester to second-year first semester with 93.37%. On the other hand, students have a lower chance of moving successfully to the next semester when they are in the first-year, first semester with 78.30% and when they are in the third-year, second semester with 73.14%. Additionally, it can be observed that the semester that a student has the highest chance of shifting to another degree program is when the student is in its first-year, first semester with 16.04% chance of shifting. It is also noted that during the first-year, first semester, the student has 5.19% chance of dropping from the program which is also the highest among the semesters.

This result is aligned with the study of González-Campos *et al.* [25]. Moreover, students who progressed successfully from the first semester up to the last semester have 88.55% chance of graduating from the BS Math program. Lastly, it was during the transition from the second-year, second semester to third-year, first semester and third-year, second semester to fourth-year, first semester where there are students who have returned to previous year level, particularly on second-year, first semester and third-year, first semester, respectively. These are the observed bottlenecks where BS Math students start to be classified as regular and irregular students. One of the possible factors that can be attributed to this event is the level of the difficulty of the core courses during these semesters such as the Advanced Calculus I, Differential Equations, and Abstract Algebra I for second-year and Modern Geometry, Number Theory, Math/Stat/CIT Electives and Cognates for third-year, most of which are pre-requisites for the next core courses. Failure to pass these courses will mean that the students will not progress to the next year's level.

The entries in the fundamental matrix N are shown in Table 2. This matrix contains the expected number of times or steps that the process is in the next transient state if it started in the transient state n_{ij}. For instance, the entry in seventh row, eighth column means that if the student is currently a fourth year enrolled in first semester, then the expected number of steps in the next transient state which is fourth-year, second semester is approximately 1 (1.0234) before being absorbed.

Table 1. State transition probability matrix P

State	1YS1	1YS2	2YS1	2YS2	3YS1	3YS2	4YS1	4YS2	G	S	D
1YS1	0.0047	0.7830	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1604	0.0519
1YS2	0.0000	0.0000	0.9337	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0361	0.0301
2YS1	0.0000	0.0000	0.0058	0.9591	0.0000	0.0000	0.0000	0.0000	0.0000	0.0175	0.0175
2YS2	0.0000	0.0000	0.0915	0.0000	0.8659	0.0000	0.0000	0.0000	0.0000	0.0183	0.0244
3YS1	0.0000	0.0000	0.0000	0.0000	0.0109	0.9511	0.0000	0.0000	0.0000	0.0109	0.0272
3YS2	0.0000	0.0000	0.0000	0.0000	0.2286	0.0000	0.7314	0.0000	0.0000	0.0000	0.0400
4YS1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0355	0.9078	0.0284	0.0000	0.0284
4YS2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0611	0.0229	0.8855	0.0000	0.0305
G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000
D	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

Note: 1YS1=first year, first semester; 1YS2=first year, second semester; 2YS1=second year, first semester; 2YS2=second year, second semester; 3YS1=third year, first semester; 3YS2=third year, second semester; 4YS1=fourth year, first semester; 4YS2=fourth year, second semester; G=graduated; S=shifter; and D=dropped.

Table 2. The fundamental matrix N for P

State	1YS1	1YS2	2YS1	2YS2	3YS1	3YS2	4YS1	4YS2
1YS1	1.0047	0.7867	0.8104	0.7773	0.8720	0.8294	0.6682	0.6209
1YS2	0.0000	1.0000	1.0301	0.9880	1.1084	1.0542	0.8494	0.7892
2YS1	0.0000	0.0000	1.1032	1.0581	1.1871	1.1290	0.9097	0.8452
2YS2	0.0000	0.0000	0.1009	1.0968	1.2305	1.1703	0.9430	0.8761
3YS1	0.0000	0.0000	0.0000	0.0000	1.2958	1.2324	0.9930	0.9225
3YS2	0.0000	0.0000	0.0000	0.0000	0.2962	1.2817	1.0327	0.9594
4YS1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.1016	1.0234
4YS2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0688	1.0874

Table 3 shows the values of probabilities of graduating, shifting, or dropping out from a given semester. The probabilities of graduation for first-year, first semester, up to fourth-year, second semester are 56.87%, 72.29%, 77.42%, 80.25%, 84.51%, 87.89%, 93.75%, and 96.48%, respectively. It shows that the probability of progressing to graduation increases as a student progress from one semester to another. On the other hand, the probability values of shifting or dropping out of the program decreases as a student moves from one semester to another semester. It can also be noted that shifting tends to be rampant in the first three semesters, while drop-outs are essentially existent even until the first semester of the fourth year. A study by Halasz and Bloom [34] indicates that a significant number of college students changed their degree program during the first two semesters or during their first year in college. The shifting of students during their first year in college might be influenced by various factors such as proximity and mobility [6], previous and current academic performance [7]–[9], parental desires, lack of interest in the degree program, perceived availability of job opportunities [35], [36] or even the COVID-19 pandemic [37] which can be explored further for the betterment of teaching-learning service delivery of PSU-Urdaneta City Campus particularly in the BS Math program and improve institutional performance.

The expected number of steps to reach an absorption state (graduated, shifted, or dropped) starting at a transient state can be gleaned in Table 4. The results were obtained after multiplying the fundamental matrix N with a column vector whose entries are all 1. To reach an absorption state, a first-year BS Math student takes approximately six to seven steps, indicating that after three semesters, a freshman BS Math student is expected to have either dropped or shifted out of the program. Meanwhile, a second-year student is expected to be 'absorbed' after six semesters, a sign that most of the second-year students would have graduated, shifted, or dropped out of the program. A fourth-year student enrolled in the second semester takes approximately one step to be absorbed, most likely graduating from the program after the said semester.

Furthermore, it can be observed that the expected times of absorption for first year students are below the minimum number of semesters required to finish the program (8 steps). This is an indication that freshmen are most susceptible to shifting and dropping out of the program. On the other hand, from the Second-year onwards, the expected number of steps before absorption is around the number of required semesters to finish the program (6 down to 1), hence, the chance of a student graduating increases as his/her stay in the program also increases.

The forecast future rates of BS Math students for the next 12 semesters are exhibited in Table 5. After eight semesters equivalent to four years, the forecast graduation rate is 35.22% which implies that there are students who retained their current year level (23.50%), and students who shifted to another degree program (22.68%) or dropped from the BS Math program (18.60%). This means that a substantial portion of students will not graduate on time or finish the BS Math program. The Pangasinan State University gives a maximum of six years to finish a four-year degree program, but after six years or twelve semesters, only 55.36% will finish the BS Math program, 22.75% will shift to another degree program, and 20.27% will drop the BS Math program for a total of 98.36%. There are still students who will be retained in the program and will need to appeal for the maximum residency policy.

Table 3. Probability matrix U

Transient state	Graduated	Shifted	Dropped
1YS1	0.5687	0.2275	0.2038
1YS2	0.7229	0.0843	0.1928
2YS1	0.7742	0.0516	0.1742
2YS2	0.8025	0.0352	0.1623
3YS1	0.8451	0.0141	0.1408
3YS2	0.8789	0.0032	0.1179
4YS1	0.9375	0.0000	0.0625
4YS2	0.9648	0.0000	0.0352

Table 4. Expected number of steps to reach an absorption state

Transient state	Expected number of steps
1YS1	6.3697
1YS2	6.8193
2YS1	6.2323
2YS2	5.4176
3YS1	4.4437
3YS2	3.5700
4YS1	2.1250
4YS2	1.1563

Table 5. Forecast future rate values for the next 12 semesters

State	1YS1	1YS2	2YS1	2YS2	3YS1	3YS2	4YS1	4YS2	G	S	D
Initial	0.0047	0.7830	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1604	0.0519
2	0.0000	0.0037	0.7311	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1894	0.0757
3	0.0000	0.0000	0.0077	0.7012	0.0000	0.0000	0.0000	0.0000	0.0000	0.2024	0.0887
4	0.0000	0.0000	0.0642	0.0074	0.6071	0.0000	0.0000	0.0000	0.0000	0.2154	0.1059
5	0.0000	0.0000	0.0011	0.0616	0.0130	0.5774	0.0000	0.0000	0.0000	0.2232	0.1237
6	0.0000	0.0000	0.0056	0.0010	0.1854	0.0124	0.4224	0.0000	0.0000	0.2245	0.1487
7	0.0000	0.0000	0.0001	0.0054	0.0057	0.1764	0.0240	0.3834	0.0120	0.2266	0.1663
8	0.0000	0.0000	0.0005	0.0001	0.0451	0.0054	0.1533	0.0306	0.3522	0.2268	0.1860
9	0.0000	0.0000	0.0000	0.0005	0.0018	0.0429	0.0113	0.1398	0.3836	0.2273	0.1928
10	0.0000	0.0000	0.0000	0.0000	0.0102	0.0017	0.0403	0.0134	0.5078	0.2273	0.1991
11	0.0000	0.0000	0.0000	0.0000	0.0005	0.0097	0.0035	0.0369	0.5208	0.2274	0.2010
12	0.0000	0.0000	0.0000	0.0000	0.0023	0.0005	0.0095	0.0040	0.5536	0.2275	0.2027

One of the main results of the study is that at least 55% of the BS Math students is expected to have finished the program after 12 semesters. This is within the expectations in the study of Aiken *et al*. [38] stating that students tend to finish an undergraduate program in 8 to 12 semesters. They further attributed this to the students' grade point average (GPA) which we could investigate further in the case of PSU–Urdaneta.

Figure 1 shows the student progression and the transition probability from the current transition state or level to the next level or previous level. The green nodes are the transition states, and the red nodes are absorbing states. A BS Math student who finished the degree on-time will have a regular student progression starting from first-year, first semester and will end at fourth-year, second semester within eight semesters, that is,

$$1Y1S \rightarrow 1Y2S \rightarrow 2Y1S \rightarrow 2Y2S \rightarrow 3Y1S \rightarrow 3Y2S \rightarrow 4Y1S \rightarrow 4Y2S \rightarrow G$$

A movement from the current transient state or semester to itself or back to the previous semester means that the student failed to pass the core courses needed to move to the next semester.

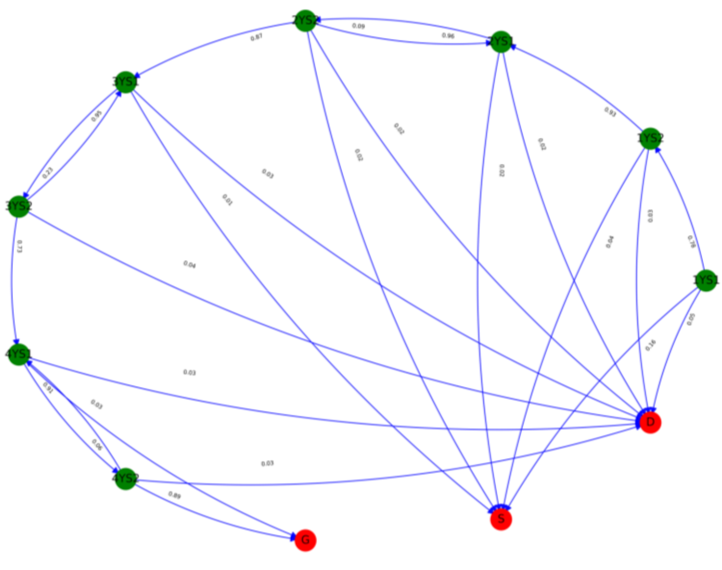

Figure 1. Markov chain transition matrix diagram to graduated, shifted, and dropped

4. CONCLUSION

The application of DTMC model in determining the progression of BS Math students is significant because it provides a probabilistic model useful in analyzing and understanding how students traverse from one state to another state, providing a more sensible interpretation of the progression of students since the probability values depend only on the current state and not on past history. The results after applying DTMC model reveal there are students who will be retained in their year level, shift to another degree program, or drop from the BS Math program. Moreover, the results show that the probability of graduating increases as the student successfully conquers the succeeding semesters while the probability of shifting and dropping decreases. It is also established that the highest risk of shifting or dropping out of the program happens during the first two semesters in college or for first year in college. After analyzing the data and generating the results, it is recommended to conduct another study that addresses the possible intrinsic and extrinsic factors that affect the graduation on time and shifting and dropping of the students especially during the first two semesters in the program. In addition, the Mathematics and Natural Sciences Department could initiate review sessions, bridging programs, and other projects and reinforcements that will help the current BS Math students' academic progress and finishing the program. This is accommodating especially for first year students who are most susceptible to shift or drop out of the program and to mitigate the bottleneck effect during the second and third years. Lastly, since the chance of graduation increases as the student stays longer in the program, the Mathematics and Natural Sciences Department may consider implementing strategic interventions and career guidance to strengthen students' interest to BS Math program, thereby decreasing the chance to drop or shift out of the program and increasing the chances of getting the elusive degree.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

ETHICAL APPROVAL

The use of students' scholastic record data needed for the completion of this study was approved by the Office of the Campus Registrar and the Campus Executive Director of Pangasinan State University Urdaneta City Campus. The students' scholastic record data were handled with strict confidentiality and high ethical considerations following the Data Privacy Act of 2012 (R.A. 10173) of the Republic of Philippines.

DATA AVAILABILITY

The final data set that supports the results and findings are available from the corresponding author [DBAG], upon reasonable request. Moreover, the data, which contain information that could identify the identity of the students and compromise their privacy, are not publicly available due to R.A. 10173.

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