

Application of artificial neural networks in assigned leadership and academic success in medical graduates

Aplicación de redes neuronales artificiales en el liderazgo asignado y el éxito académico en egresados de medicina

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Abstract

Objective: To apply an artificial neural networks analysis (ANN) model to identify variables that predict assigned leadership and academic success in graduates of six generations of medical school. **Method:** Analytical, retrospective, comparative study. A total of 1434 graduates participated. A questionnaire was sent to them by e-mail including a voluntary participation consent. A multivariate statistical analysis using multi-layer perceptron ANN, decision trees and driver analysis was performed. **Results:** The ANN identified seven independent variables that predicted professional success and eight for leadership in medical graduates. The decision trees identified significant differences in the variables professional performance ($p = 0.000$), age ($p = 0.005$) and continuing education activities ($p = 0.034$) related to professional success, and for leadership the variables gender ($p = 0.000$), high school grades ($p = 0.042$), performing clinical practice during the social service year ($p = 0.002$) and continuing education activities ($p = 0.011$). **Conclusions:** The ANN identified the main independent predictor variables of professional success and leadership of the graduates. This study opens up two new lines of research little studied with the techniques of in the area of medicine.

Keywords: Medical career. Graduate follow-up. Leadership. Academic success. Artificial neural networks.

Resumen

Objetivo: Aplicar un modelo de análisis de redes neuronales artificiales (RNA) para identificar las variables que predicen el liderazgo asignado y el éxito académico en egresados de seis generaciones de la carrera de Medicina. **Método:** Estudio analítico, retrospectivo y comparativo. Participaron 1434 egresados. Se envió un cuestionario por correo electrónico que incluyó el consentimiento de participación voluntaria. Se realizó análisis estadístico multivariado mediante RNA del tipo perceptrón multicapa, árboles de decisión y análisis de impulsores. **Resultados:** Las RNA identificaron siete variables independientes que predijeron el éxito profesional y ocho para el liderazgo en los médicos egresados. Los árboles de decisión identificaron diferencias significativas en las variables desempeño profesional ($p = 0.000$), edad ($p = 0.005$) y actividades de educación continua ($p = 0.034$) relacionadas con el éxito profesional, y para el liderazgo las variables sexo ($p = 0.000$), promedio en el bachillerato ($p = 0.042$), realizar práctica clínica en el servicio social ($p = 0.002$) y actividades de educación continua ($p = 0.011$). **Conclusiones:** Las RNA identificaron las principales variables independientes predictoras del éxito profesional y el liderazgo de los egresados. El estudio abre dos líneas de investigación poco estudiadas con las técnicas de RNA en el área de la medicina.

Palabras clave: Carrera de Medicina. Seguimiento de egresados. Liderazgo. Éxito académico. Redes neuronales artificiales.

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Introduction

For Universidad Nacional Autónoma de México (UNAM), and particularly its School of Medicine, follow-up studies of graduates represent a very important area thanks to the information obtained from students who graduate from their study programs, and their potential impact on the professional, educational, and social practice in Mexico. In UNAM School of Medicine current study plan (plan 2010), follow-up studies of graduates are included to obtain information on the following general areas: job market, professional profile, access to the national medical residency system, and academic and professional performance. The same study plan emphasizes the need to conduct comparative studies of its graduates in their professional performance. Technically, follow-up studies are not easy to conduct due to the geographical dispersion of graduates and their various workplaces, whether in the public or private sector, medical administration, and management, among other factors. For these reasons, this follow-up study aimed at investigating 2 important areas on the Medical School: leadership and academic success. The approach to studying these 2 aspects is predictive, using multivariate techniques that have been increasingly used in medical education research: artificial neural networks (ANN).

ANNs are information processing systems whose structure and function are inspired by biological neural networks¹. The term “neural network” is applied to a family of models characterized by a large parameter space and flexible structure, derived from studies on the functioning of the brain².

A neural network is defined as a set of simple processing elements called nodes or neurons, which are interconnected by connections with modifiable numeric values, called weights¹. Depending on the relationship model, there can be 1 or more layers, or nodes that are hidden or not visible, which communicate with each other, making synaptic weights not easily to interpret.

In a neural network with a set of variables, it is important to understand the general architecture of the network. There are 2 main types: the multi-layer perceptron network and the radial basis function network. Both are predictor functions, also called inputs or independent variables, which minimize the prediction error of the target variables (dependent or output variables).

Unlike linear regression, characterized by a rigid model and assumptions, neural networks are flexible. Also, they do not make a priori assumptions on the

type of relationships that exist between independent and dependent variables or require theoretical assumptions on data distribution either. Instead, the shape of the relationships between variables is determined during the learning process of the neural network itself, meaning that neural networks learn by themselves.

Figure 1 illustrates the basic architecture of an ANN. The inputs are predictors, or independent variables, and the output layer consists of all categories of response for the dependent variable. The hidden layer are the nodes, or units not observable in the relationships between variables, which are formed by the forces or interconnection weights between neurons (arrows in Fig. 1). An example of this, a few dotted lines in a lighter color are shown, which are interpreted as having lower weights, i.e., lower predictive value.

Therefore, a neural network is a massively parallel distributed processor with a natural propensity to store experimental knowledge and make it available for use. It resembles the brain in 2 aspects: 1) knowledge is acquired by the network through a learning process, and 2) interneuronal connection strengths, known as synaptic weights, are used to store knowledge².

In medicine and education, studies have been reported in which ANNs have been applied as a multivariate prediction technique. In medicine, various studies have been conducted on this topic^{1,3-10}, and in education, ANNs have mainly been used to predict student performance, academic success, and the selection of medical residency candidates¹¹⁻²³. However, no studies have ever been conducted of ANNs used to predict leadership in students.

In the present study, since we aimed at using the ANN technique, no in-depth review of the concepts related to leadership and the success of graduates in the field of Medicine was ever conducted. In any case, readers are referred to the consulted works on success and leadership for further reference²⁴⁻³¹. Notably, the study conducted by Sánchez²⁵ in 2015 stands out, who conducted a literature narrative review on leadership (which is complex to define and has multiple definitions in the literature) and highlighted the characteristics of leadership as a trait vs process or assigned vs emergent leadership. In the present study, the type of leadership under consideration is assigned leadership. On the other hand, Gatica et al.²⁴ analyzed the variables associated with academic success in undergraduate students at UNAM Medical School.

The objective of this study was to apply an ANN analysis model to identify the variables that predict

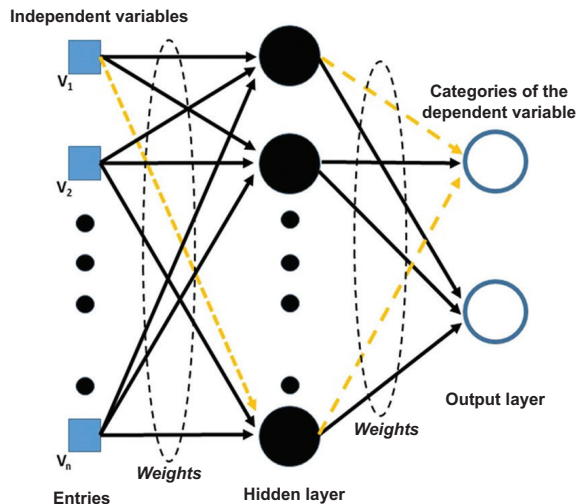


Figure 1. Basic architecture of an artificial neural network.

assigned leadership and academic success in graduates from 6 generations of the medical degree program at UNAM Medical School.

Method

This was a multivariate, analytical, retrospective, and comparative study of 1434 graduate students from the medical degree from the 2004-2009 generations graduated at UNAM Medical School. A questionnaire with 62 variables was sent, with 29 independent variables distributed across 8 different areas: demographics, family, student's educational background in middle and high school, failure in subjects, suspension of studies, opinions on the curriculum of the medical program, admission to medical postgraduate programs, the job market, and professional performance in the public or private sector. The dependent variables were academic (professional) success and assigned leadership activities.

Operational definitions

In the study, assigned leadership was regarded as having served as a student technical advisor at the Medical School, a group leader or representative, or a student leader in academic events during the medical degree. Academic (professional) success was regarded as holding managerial or middle management positions, professional recognition by peers, and satisfaction with the economic income received after graduating. The questionnaire content was validated

by 8 faculty members from the Medical School with over 10 years of teaching experience.

It was deemed relevant that for the follow-up studies of the graduates, at least, 5 years should have gone by since graduation to assess the professional development achieved with some stability in their careers. For this reason, the generations of graduates who obtained their medical degree from 2004 through 2009 were selected. Therefore, the latest generation (2009) had graduated, at least, 6.5 years ago.

Data curation method

An e-mail was sent to all graduates inviting them to participate in the study voluntarily and answer an electronic questionnaire. The e-mail addresses of the graduates were provided by the Medical School Office of Academic Services. The invitation included the objective of the study, its academic importance, and voluntary consent form to respond to the attached questionnaire. A period of 2 to 10 months (from August 2017 through April 2018) was given to obtain responses. Questionnaires were administered in person to those graduates who did not wish to respond electronically, but who were willing to participate.

Statistical analysis

The information obtained was stored in the statistical program SPSS v.25. Multivariate statistical analysis was performed using data mining techniques: multilayer perceptron neural networks (ANN), decision trees (DT), and boosted trees (BT). These 3 analysis techniques combined were used to determine the most important variables which, in their combined and synergistic interaction, predicted (ANN), classified and compared the response categories (DT), and determined the performance coefficients (BT). These techniques were applied to the response categories of assigned leadership during the undergraduate program and academic success during the graduates' professional performance and practice. Due to its technical and methodological importance,² to reproduce the ANN model used, table 1 describes the parameters and specifications used to calculate the neural network model.

Ethical considerations

The project was approved by UNAM Medical School Research Division Research and Ethics Committee, with registration no. 04-2013. A consent form for voluntary

Table 1. Parameters and specifications of the calculated neural network model

Parameter	Specifications
Type of neural network	Multilayer perceptron
Independent variables (Factors)	29 variables
Dependent variables	Assigned leadership and academic success
Initial model point	Fixed random
No. of processed and calculated models	10 models (selection of the model with the lowest entropy error)
Sample partitions	Training 70%, testing 30%, and reserved 0%
Architecture	Automatic selection
Hidden layers	1
Training	Supervised, batch
Optimization algorithm	Scaled conjugate gradient
Initial lambda	0.0000005
Initial sigma	0.00005

participation in the study was e-mailed to the 1434 graduate students. The study fully complied with the ethical research recommendations in education, including the Ethical Standards of the American Educational Research Association³², the Code of Professional Responsibilities in Educational Measurement by the National Council of Measurement in Education³³, the Code of Fair Testing Practices in Education³⁴, and the Universal Declaration on Bioethics and Human Rights³⁵.

Results

Information was obtained from 1434 graduates from UNAM Medical School, spanning 6 generations (2004-2009). Two former works were conducted with the same graduate students: the first one was a descriptive study³⁶ including the overall profile of the 1434 graduates, educational backgrounds, career aspects, and satisfaction with professional training. The second study analyzed phenomena related to subject failure and discontinuous trajectories through multivariate discriminant analysis³⁷.

Table 2 illustrates the results of entropy error, incorrect forecasts, and the area under the ROC (Receiver Operating Characteristic) curve obtained

from the calculated ANN, both for academic success and assigned leadership. This table 2 also illustrates that Model 1 was the best suited for professional success (entropy error, 176.5 in the training sample), while Model 6 was the best suited one for assigned leadership (entropy error, 527.5 in the same type of sample).

To identify the most important independent variables and their correlation with the dependent variable of professional success, performance coefficients of the chosen ANN model (no. 1 in table 2) were calculated. For this purpose, a BT analysis was performed, assigning values to variables (in standardized z-units) based on their level of importance and performance. Table 3 shows the performance coefficients of the most important and well-evaluated independent variables that predicted academic (professional) success, as obtained in figure 2 (upper right quadrant).

Additionally, a CHAID (Chi-Squared Automatic Interaction Detector) type DT analysis was conducted, comparing the categories of all independent variables, and selecting only those where significant differences were found. Figure 3 illustrates the DT with the CHAID analysis calculated for the independent variables that showed statistically significant differences in the graduates' academic success.

The most important variables with statistically significant differences regarding academic success included good professional performance ($p = 0.000$), being 34 years of age or younger ($p = 0.005$) and participating in 1 or more activities of continuous medical education per year ($p = 0.034$). The correct classification of predicted cases according to the observed cases in the DT was 100%.

Similarly, to identify the most important independent variables and their correlation with the dependent variable "assigned leadership," performance coefficients of the chosen model (no. 6 in table 2) were calculated. Table 4 shows the performance coefficients of the most important and well-evaluated independent variables that predicted assigned leadership, as shown in figure 4.

Figure 5 illustrates the CHAID and DT analysis calculated for the independent variables that showed statistically significant differences in assigned leadership among graduates. The most important variables in which statistically significant differences related to assigned leadership were found included gender ($p = 0.000$), in women, performing clinical practice activities during social service ($p = 0.000$) and having a mean high school GPA of 9 to 10 ($p = 0.042$). In men, performing clinical practice activities during social

Table 2. Calculated models of ANNs and their values obtained for entropy error, incorrect predictions, and areas under the ROC curve

Academic success (professional)						
ANN	Entropy error		Incorrect prognosis (%)		Area under the ROC curve* (%)	
Model	Training	Test	Training	Test	Managerial position and better income	Professional recognition and enjoying the work done
M1	176.5	80.5	5.0	4.9	72.1	72.1
M2	193.0	78.1	5.0	4.8	65.8	65.8
M3	196.7	72.1	5.1	4.5	66.8	66.8
M4	195.4	74.8	5.1	4.5	66.3	66.3
M5	195.2	80.7	5.1	4.6	63.5	63.5
M6	200.0	68.0	5.4	3.9	68.2	68.2
M7	197.2	82.3	5.0	4.8	60.7	60.7
M8	183.5	83.6	4.9	5.1	68.6	68.6
M9	209.5	53.1	5.5	3.6	70.0	70.0
M10	180.0	87.5	4.9	5.1	68.8	68.8

Assigned leadership						
Model	Entropy error		Incorrect prognosis (%)		Area under the ROC curve * (%)	
	Training	Test	Training	Test	Technical advisor, team leader	None
M1	565.5	236.5	28.4	25.9	67.4	67.4
M2	554.3	252.6	27.8	27.3	67.0	67.0
M3	559.1	237.1	26.2	28.1	68.6	68.6
M4	553.6	248.1	28.9	26.4	67.8	67.8
M5	577.2	216.0	29.5	25.0	69.7	69.7
M6	527.5	264.8	26.9	28.5	69.0	69.0
M7	549.6	261.8	28.1	27.6	65.8	65.8
M8	677.3	227.6	27.3	27.7	67.4	67.4
M9	561.3	239.6	27.6	27.1	68.2	68.2
M10	552.1	241.8	27.8	27.0	69.3	69.3

*The ROC curve provides the level of performance of the ANN model.
ANN: artificial neural network.

service ($p = 0.002$) and participating in 1 or more activities of continuous medical education per year ($p = 0.011$) were significant. In this CHAID analysis, the correct classification of predicted vs observed cases in DT was 71.9%.

Discussion

In the field of medicine, ANN techniques have been used for various purposes: Montañó¹ used them in his

doctoral thesis for survival analysis and addictive behaviors; Trujillano et al.^{3,6,7} reported on their use primarily to predict quantitative measurements of patients in medical practice (mortality, survival, diagnosis, image processing, electrocardiograms, electroencephalograms, optimal drug dosages, intensive care medicine, and hospital mortality); Hernández and Lorente,⁸ and Ortiz et al.⁹ used ANN techniques for predictive studies of factors associated with breast cancer; Palmer et al.,¹⁰ used ANN techniques to predict ecstasy consumption;

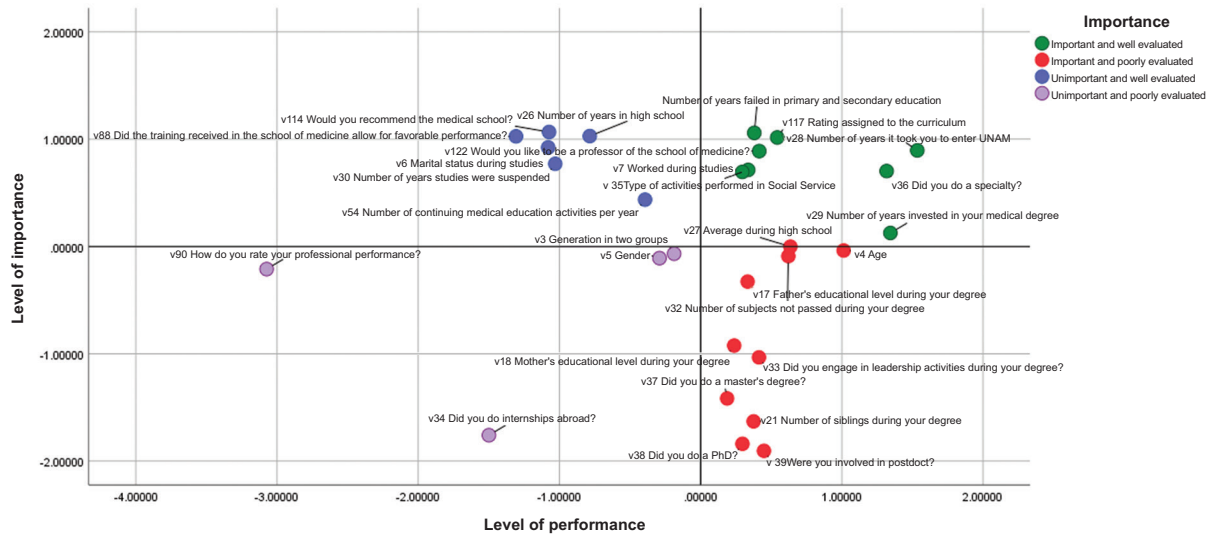


Figure 2. Independent variables based on their level of importance and performance in predicting professional success.

Table 3. Coefficients of performance of predictor variables for academic success

Performance coefficients (Boosted tree)	Most important and well-assessed independent variables that predicted academic success	Performance coefficients (Boosted tree)
0.98	Would you recommend this Medical School?	0.98
0.97	No. of years of high school attendance	0.97
0.97	Did the training received at the Medical School allow favorable professional performance?	0.97
0.93	Marital status during studies	0.93
0.92	Would you like to become a professor at the Medical School?	0.92
0.88	No. of years of suspension of studies in the medical program	0.88
0.77	No. of continuing medical education activities per year	0.77

Table 4. Coefficients of performance of predictor variables for assigned leadership

Performance coefficients (Boosted tree)	Most important and well-assessed independent variables that predicted assigned leadership
0.98	Would you recommend the Medical School?
0.97	No. of years of high school attendance
0.97	Rating assigned to the curriculum you studied at the Medical School
0.93	Marital status during studies
0.93	Years it took you to enter UNAM
0.92	Would you like to become a professor at the Medical School?
0.88	No. of years of suspension of studies in the medical degree
0.77	No. of continuing medical education activities per year

and Menacho³⁸ to predict academic performance. Additionally, Basogain³⁹ mentions various applications of ANN in medicine (image processing, medical diagnosis, robotics, and classification of data from sensors). These referenced works used ANNs for aspects of medical practice, with a relatively small no. of variables, primarily quantitative, on a continuous or ratio scale.

With the development of both open-source and proprietary software in the current century, ANNs have ventured into the social sciences. In the field of education, particularly in medicine, few works have been published on ANNs. Menacho³⁸ used ANNs to predict the academic performance of medical students using school-related variables. Other authors have also used them, primarily to forecast academic performance in various areas: Cataldi et al.¹¹ used ANNs to predict academic performance in a sample of 450 undergraduate students; Zacharis¹² studied the academic

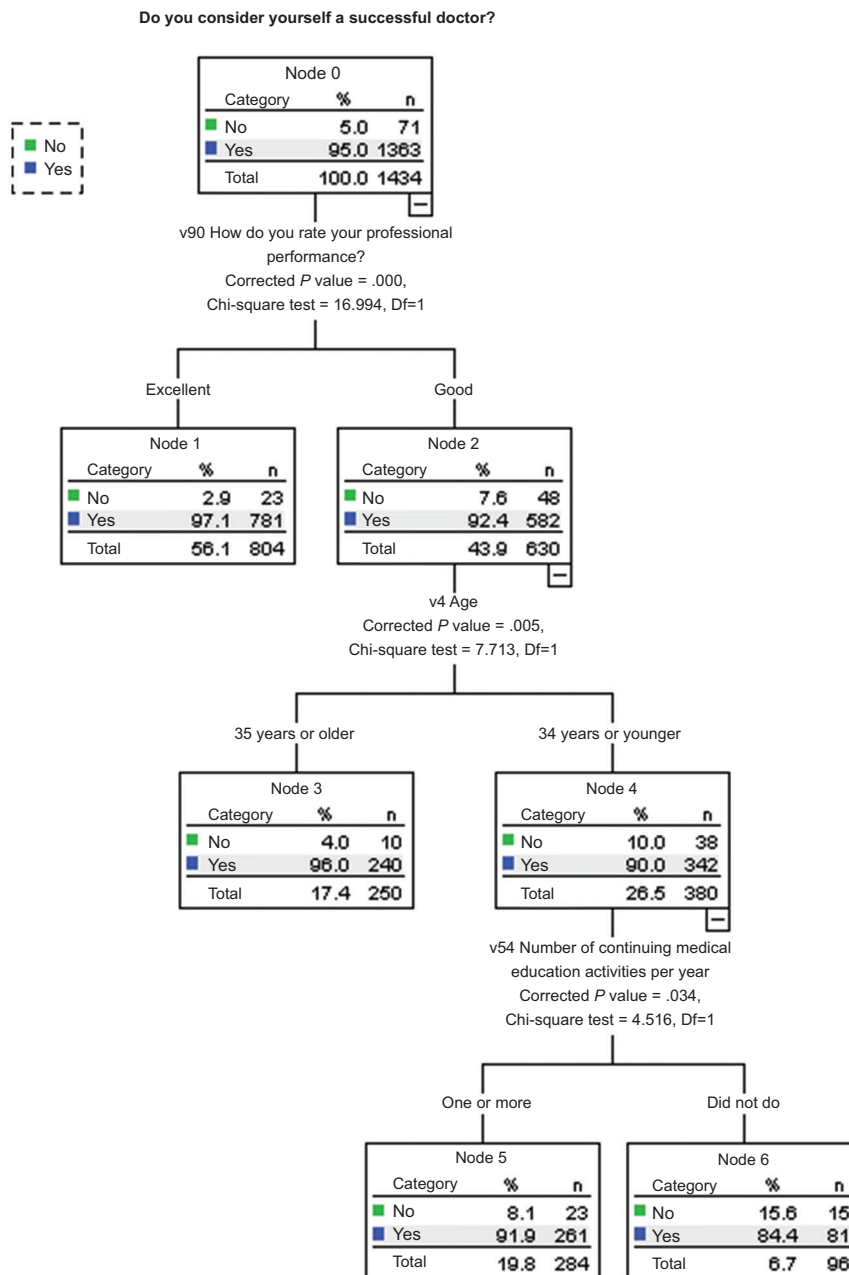


Figure 3. Decision tree of independent variables that showed significant differences associated with professional success.

performance of 265 college students of mechanical engineering; and Sagueiro et al.¹³ reported on their progress using ANNs to predict the abilities of college students. Apparently, studies using ANNs have a certain preference for predicting academic performance or achievement as confirmed in the research from Ahmad and Shahzadi¹⁵, Bahadir¹⁶, and Baashar et al.¹⁷ We should mention that most of these authors consider the grades obtained in the subjects taken by the students as the main independent variables in their ANN

models. Our study examined 29 variables distributed across 8 different areas described in the section "Method" above.

Regarding academic success, Agdelen et al.¹⁴ studied a total of 154 first-grade students of engineering and architecture at college level. They included 20 independent variables (social, economic conditions, and environmental factors) in their ANN model, and the dependent variable was categorized into 5 levels of academic success, without specifying the names of

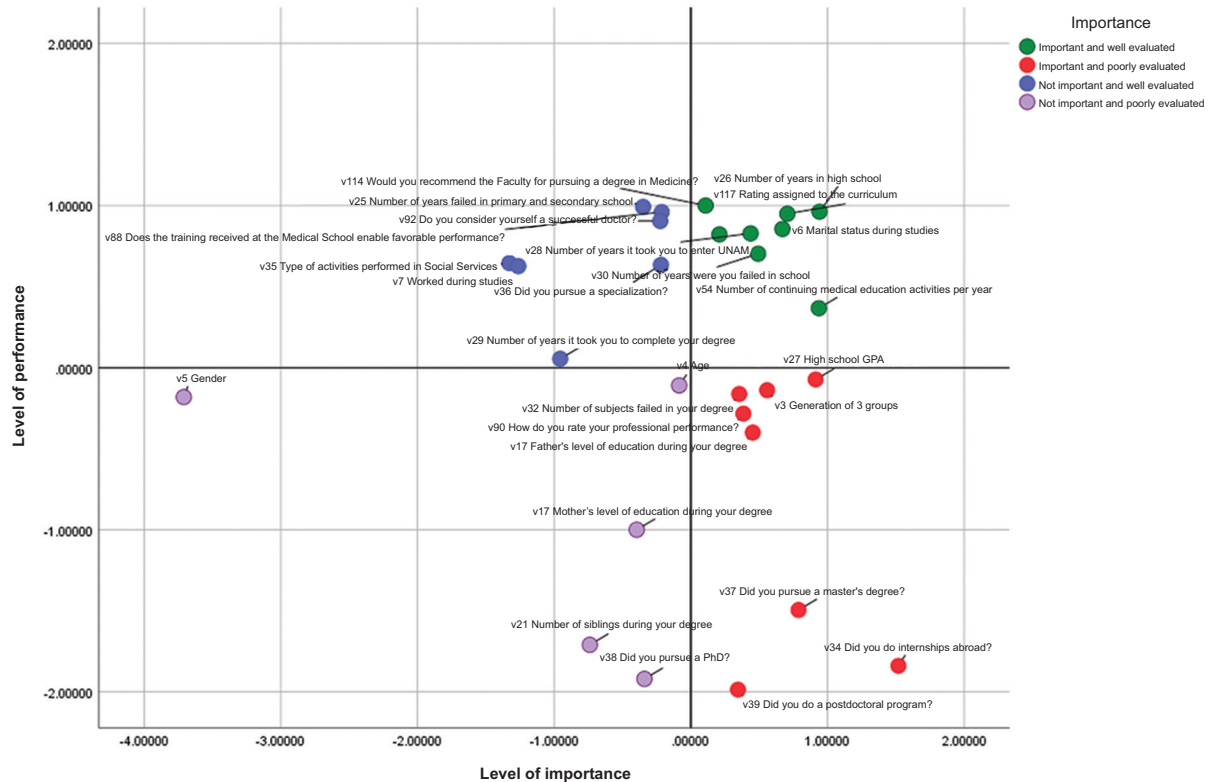


Figure 4. Independent variables based on their level of importance and performance in predicting assigned leadership.

these predictive categories. These authors used a radial basis function type ANN model; our study used the multilayer perceptron type because it is supervised and provided a better interpretation of the results. The mentioned authors¹⁴ only calculated one ANN model, but with different rates of the training and test samples. In the present research, a total of 10 random models were calculated with the same fixed rates of training (70%) and test (30%), as mentioned in the “Statistical analysis” section above. These same authors¹⁴ cite Büyüköztürk and Deryakulu (2002), Begik (1997), Parke and Welsh (1998), and Perçin (1998) as other researchers who studied academic success; however, they did not use the ANN technique but primarily resorted to linear regression.

López et al.¹⁹ conducted a study among 1614 college students majoring in biochemistry, in which they analyzed 8 independent variables to predict academic performance. The authors used both types of ANNs (multilayer perceptron and radial basis function) with the same variables and concluded that while both types had good predictive capacity, the adjustments provided by the multilayer perceptron networks were superior to those obtained with the radial basis function networks. Borracci and Arribalzaga¹⁸ used ANNs for the

classification and selection of candidates for medical residencies, while Porcel et al.²⁰ and Acosta and Pizarro²³ used ANNs to predict academic performance.

Regarding assigned leadership in the field of medicine, no publications were found using ANNs. The consulted works mainly focused on the conceptualization, types, importance, teaching in medical school, and other characteristics related to leadership training in the medical field^{24,25,27-31}.

As for the limitations of the present study, we should mention that the results obtained cannot be generalized since, although the sample of graduates was large (1434 medical graduates from 6 generations), it was not random or voluntary. Another bias inherent to retrospective surveys is the possibility of obtaining information that cannot be verified, but which is acknowledged to have existed. Another limitation was the operational definition of the 2 dependent variables (assigned leadership and academic success); graduates gave their responses based on events or facts through their own opinions or personal perceptions.

Regarding the limitations of the ANN technique used, the results depend on several elements: the number and order of input (independent) variables, the random

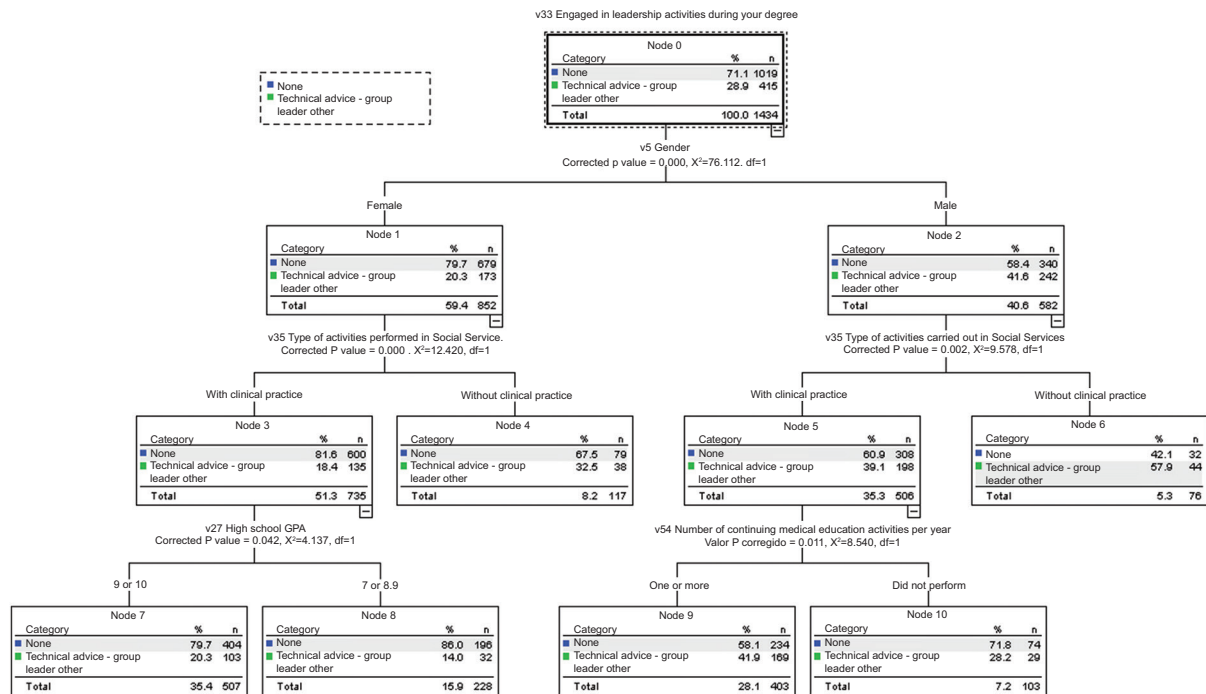


Figure 5. Decision tree of independent variables that showed significant differences associated with assigned leadership.

starting point of the model, and the order of the categories introduced into the independent variables. Another limitation is that ANNs assign pseudo-probability values⁴⁰ to variables that are predictors of the dependent variable, which means that they need to be complemented with more robust methods that do quantify the value of the performance coefficients seen in Figs. 2 and 4, such as CHAID-type DT⁴¹ (Figs. 3 and 5) and BT⁴².

Among the strengths of this study, we should mention that 10 random ANN models were calculated, and the best model was selected based on the lowest entropy error. The rationale for this decision is that the calculated network learns by itself by examining individual records (70% of the sample in this study), generating a prediction for each record, and making weight adjustments when it gets a prediction wrong⁴⁰. This process is repeated many times, and the network continues to improve its predictions until it reaches 1 or more stop criteria considering the values of the lambda and sigma optimization algorithm specified in table 1.

To verify and validate the results of the 10 calculated models and ensure the consistency of the values obtained, a fixed random starting number in the statistical program was selected. Although these aspects were not mentioned in the consulted articles, they are considered important and necessary to verify the results obtained from the calculated models and make sure that readers

understand the parameters used in the study, whose design and neural network architecture are described in the "Method" section above and specified in table 1.

Another strength is the size of the study sample, which we consider large (1434 graduates). This characteristic increases the predictive capacity of the ANN technique since 70% of the sample was used to "train" the ANN and "learn" to predict the relationships between independent and dependent variables. The supplementary analysis on the importance and performance of the independent variables (BT) allowed us to obtain performance coefficients; their highest values clearly identified the main independent predictor variables (7 variables for success and 8 for leadership).

Calculating 10 ANN models allowed us to choose the one with the lowest entropy error, which is shown in the ROC curves that explain the expected performance of a classifier according to the areas under the curve, always ranging between 0 and 1; the higher the value, the better the classifier, and the higher the rate of correctly classified individuals (Table 2).

Another strength is having complemented the ANN with a CHAID-type DT analysis⁴¹ to identify significant nested variables, and BT⁴¹ to determine performance coefficients. These techniques allowed for a better understanding and interpretation of the ANN results.

Finally, an additional strength is having followed the general guidelines recommended by the National Association of Universities and Higher Education Institutions⁴³ on the waiting period for graduates from the program (at least 5 years) before conducting follow-up studies.

Conclusions

This study is consistent with the current curriculum guidelines of UNAM School of Medicine, which emphasizes the importance of conducting follow-up research on its graduates to strengthen and make curricular adjustments⁴⁴.

The ANN identified the main variables that predicted academic success and assigned leadership roles among the medical graduates. The ANN technique is straightforward and statistically favorable as it does not require the robust theoretical assumptions of linear regression analysis. However, it is advisable to have theoretical training in neural networks for its use. Additionally, ANN analysis should be complemented with other statistical techniques, such as BT to measure performance coefficients and DT (nested significant independent variables) to identify the specific weight and statistical significance of predictor variables in more detail and depth.

The use of the multilayer perceptron-type ANN technique in this study identified the main independent predictor variables (7 for success and 8 for leadership). Furthermore, the study delved into 2 less-studied research areas in the field of medicine using ANN techniques.

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Conflicts of interest

None declared.

Ethical disclosures

Protection of human and animal subjects. The authors declare that no experiments were performed on humans or animals for this study.

Confidentiality of data. The authors declare that they have followed the protocols of their work center on the publication of patient data.

Right to privacy and informed consent. The authors have obtained approval from the Ethics Committee for analysis and publication of routinely acquired clinical data and informed consent was not required for this retrospective observational study.

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