# Artificial Neural Networks and Medical Education

# As Redes Neurais Artificiais e o Ensino da Medicina

Rodrigo Siqueira-Batista[I]
Rodrigo Roger Vitorino[II]
Andréia Patrícia Gomes[III]
Alcione de Paiva Oliveira[III]
Ricardo dos Santos Ferreira[III]
Vanderson Esperidião-Antonio[III]
Luiz Alberto Santana[III]
Fabio Ribeiro Cerqueira[III]

**ABSTRACT**

*The transformations that medical practice has undergone in recent years – especially with the incorporation of new information technologies – point to the need to broaden discussions on the teaching--learning process in medical education. The use of new computer technologies in medical education has shown many advantages in the process of acquiring skills in problem solving, which encourages creativity, critical thinking, curiosity and scientific spirit. In this context, it is important to highlight artificial neural networks (ANN) – computer systems with a mathematical structure inspired by the human brain – which proved to be useful in the evaluation process and the acquisition of knowledge among medical students. The purpose of this communication is to review aspects of the application of ANN in medical education.*

**PALAVRAS-CHAVE**

- Educação Médica;
- Redes Neurais Artificiais;
- Medicina.

**RESUMO**

*As transformações da prática médica nos últimos anos – sobretudo com a incorporação de novas tecnologias da informação – apontam a necessidade de ampliar as discussões sobre o processo ensino-aprendizagem na educação médica. A utilização de novas tecnologias computacionais no ensino médico tem demonstrado inúmeras vantagens no processo de aquisição de habilidades para a identificação e a resolução de problemas, o que estimula a criatividade, o senso crítico, a curiosidade e o espírito científico. Nesse contexto, ganham destaque as Redes Neurais Artificiais (RNA) – sistemas computacionais cuja estrutura matemática é inspirada no funcionamento do cérebro humano –, as quais têm sido úteis no processo ensino-aprendizagem e na avaliação de estudantes de Medicina. Com base nessas ponderações, o escopo da presente comunicação é revisar aspectos da aplicação das RNA na educação médica.*

**KEYWORDS**

- Medical Education;
- Artificial Neural Networks;
- Medicine.

Recebido em: 28/03/2013

Reencaminhado em: 20/04/2014

Aprovado em: 20/08/2014

[I] *Universidade Federal de Viçosa, Viçosa, MG, Brasil; Universidade Federal do Rio de Janeiro, Rio de Janeiro, RJ; Brasil.*
[II] *Pontifícia Universidade Católica de Campinas, Campinas, SP, Brasil.*
[III] *Universidade Federal de Viçosa, Viçosa, MG; Brasil.*

## INTRODUCTION

The many faces of medicine—care and prevention, episteme/knowledge and techne/art, reason and intuition—have been walking hand in hand in the West since their birth in Ancient Greece[1]. Technological advancements in the last hundred years have made increasingly necessary to debate the relationship between medicine and biotechnoscience[2]—highlighting the issues concerning the access to new information. Such debates must involve generalists and specialists that will deal (actually in many a circumstance have been dealing already) in the near future with numberless advancements—until recently unimaginable—including new methods of transplant, minimally invasive surgeries, nanomedicine, telemedicine and robotic surgery[3,4]. These frontiers certainly appear as possibilities of maximizing quality of care to the ill, a dimension pursued by those who—with art, zeal, human and social commitment—practice medicine.

As in any techne/episteme[5], the progress and the act of finding answers bring in tow a tangle of new questions that previously could not even be formulated. It becomes indeed crucial to approach medical education within the scope of the current biotechnoscientific changes, discussing the concepts that are nowadays relevant, despite the fact that they may seem distant to the colleague that practices medicine daily.

In this context, Artificial Neural Networks (ANNs)—a form of non algorithmic computational models characterized by systems that to some degree resemble the structure of the human brain[6,7]—gain relevance due to their potential to medicine. The ANN are parallel distributed systems composed of simple processing units—usually called artificial neurons in analogy to biological neurons— arranged in one or more layers and interlinked by multiple connections[8].

Its architecture provides outstanding performance since the usual process of problem solving is based on learning and generalizations, which are provided by adapting its parameters to a set of patterns previously presented[9]. The ability to generalize—in other words, to learn through a set of examples and give coherent answers to unknown data—makes it possible to solve complex computational problems.

The excellent performance of ANNs—which for several types of problems prove to be far superior to conventional computer models—has contributed to the advancement of various playing fields in the clinical practice[10]. Examples of significant results with the application of ANNs in problems of the medical field are: Support in diagnosis, prediction of risk and prognosis, interpretation of diagnostic methods, development of epidemiologic researches, among others[11,12].

Based on these brief considerations, the objective of this paper is to present a literature review about the applicability of ANNs in medical education.

## METHODS

The present work was built based on a literature review with defined search strategy. The U.S. National Library of Medicine (PubMed) and the Scientific Electronic Library on Line (SciELO) were consulted for the period between 1/1/1990 to 31/12/2013. The terms used were:

Strategy 1: *Medical Education + Artificial Neural Networks*;
Strategy 2: *Artificial Neural Networks*;
Strategy 3: *Artificial Neural Networks + Medicine*.

Besides the articles, reference books, PhD theses, Masters dissertations, guidelines and official documents related to the theme—more specifically to medical education and the health field—were consulted.

The research allowed to identify 3.578 citations—their distribution is found on table 1— among which 35 manuscripts were selected.

**Quadro 1: Número de artigos obtidos na pesquisa bibliográfica**

| Search Strategy* | Consulted Base | |
|---|---|---|
| | PubMed* | SciELO Brazil |
| Strategy 1 – Medical education + Artificial Neural Networks | 3 | 0 |
| Strategy 2 – Artificial Neural Networks | 3.217 | 50 |
| Strategy 3 – Artificial Neural Networks + Medicine | 308 | 0 |

** Upper bound for publication date in the search: 31/12/20013.*

The eligibility criterion of choice was the exposition of the ANN applicability in medical education.

## RESULTS AND DISCUSSION

After reading and analyzing the chosen texts, the collected notes were organized in three sections—medical education and the new technologies; artificial neural networks; artificial neural networks: Uses in medical education—presented hereafter.

## MEDICAL EDUCATION AND THE NEW TECHNOLOGIES

Particularly in Brazil, the Constitution[13], promulgated in October 5, 1988, shows a markedly progressive dimension concerning health, stated particularly in the article 196 which determines the State's role as follows:

> *Health is a right of all and a duty of the State, guaranteed by means of social and economic policies aimed at both reducing the risk of illnesses and other grievances and ensuring the universal and egalitarian access to actions and services that promote, protect and recover it (p. 33).*

In this same vanguard movement The Unified Health System (SUS)[14] is created, having for foundation the article 198 that states[13]:

> *The public health actions and services integrate a hierarchical regionalized network and constitute a single system organized according to the following guidelines:*
> *I—decentralization, with one only direction in each sphere of government;*
> *II—comprehensive health care, with priority given to preventive actions, without prejudice to care services;*
> *III—community engagement (p. 33-34).*

In order to establish parameters able to guarantee with exactness the training of a professional apt to offer the envisaged quality services, the Resolution CNE/CES No 4, November 7, 2001, that institutes the National Curriculum Guidelines for the Undergraduate Course in Medicine[15], in its article 3º, proposes the profile:

> *The undergraduate Course in Medicine has as the egress graduate/professional profile, the physician, trained as generalist, humanist, critical and reflexive, able to act guided by ethical principles in the health—disease process in its different levels of care, with health promotion, prevention, recovery and rehabilitation actions, in a comprehensive care perspective, with sense of social responsibility and commitment to citizenship, as a promoter of the human being integral health (p.1).*

To achieve these objectives one should have a clear understanding of the need to broaden the indispensable skills for the present reality of the working world, which in a globalized context—of rapidly spread information and increasingly complex science—demands different competencies from the ones previously considered for practicing the profession[16]. This is not exclusively about the abilities for the medical practice, but also, about the capabilities that are relevant to all health care professionals, like a new approach to interpreting reality, dealing with scientific concepts and benefiting from the technological potentialities in a responsible way, vital conditions to follow the rapid pace of advancements in society.

Educating is essentially forming[17, 18]. Thus, the role both of the educator and the Educational Institutions is certainly not restricted to offering information and much less reducing the educational experience to mere technical training[17]. It falls to the man/woman who teaches/learns another man/woman the building of a true subject-subject relationship, educator/pupil[19]. It is the *praxis* that implies action/reflection from men/women upon the world to transform it. This scenario provides room for new teaching-learning methodologies and, equally, new forms to create, teach and practice medicine[20, 21 22]. Indeed, it is imperative to the twenty-first century professional to coadunate human and technological know-how[22,23].

In the last three decades the health care model has suffered several changes, mainly by the incorporation of computer science to medicine, with consequences both to the production of knowledge and the medical practice[24]. The unfolding of new nuances in understanding the health-disease process—the holistic approach to the human being, the environmental role in determining sickness, the advancements in scientific knowledge and the development of increasingly complex guidelines and protocols for diagnosis and treatment of diseases—all point to the challenge of creating ways to apprehend them[25].

The uses of ANNs in medicine gain relevance in such context, insofar as their potential for the solution of problems in various biomedical domains has been investigated[26,27]. This technological resource has reached growing relevance and applicability both in teaching and evaluation in medical school, being used in numberless situations when there is a relationship between variables—inputs—and predictive results—outputs[8]. Four basic fields are noteworthy: Modulation (simulation of brain function and neurosensory organs);

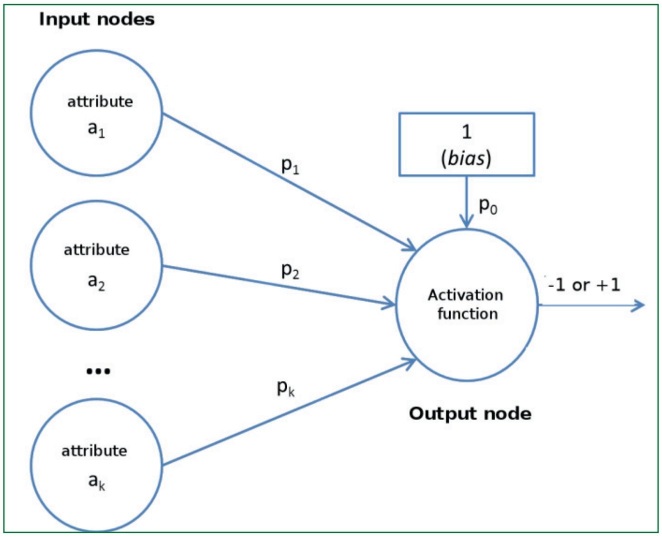
processing bioelectric signals (filtering and evaluation); diagnosis (control and checking of answers and interpretation of results); prognostics (retrospective analysis of stored information)[11,28].

## ARTIFICIAL NEURAL NETWORKS

ANNs are computational systems with a mathematical-logic structure inspired in human neurophysiology[6]. Data processing starts with a *learning* phase in which a set of data—of already known answers—is presented, altering the forces of connection in the network in such a way that the ANN answers are as similar as possible to the answers observed in the training data. It is expected that subsequently the ANN acquires the ability to generalize, that is, the capability to furnish answers to previously unknown data[8].

The study of ANNs is an attempt to imitate biological neural systems, with the objective of building powerful automated learning techniques[29,32]. In a way similar to the *H. sapiens sapiens* brain, an ANN is composed of a set of nodes interconnected by routed links. The first method proposed for an ANN was called *perceptron*[33]. In this model of fairly simple architecture, only two types of nodes are present: Input nodes and one output node. Nodes of the first type represent the attributes of training examples—as well as the instances that will be submitted for classification by the network. The output node represents the classification of the instance in question. Besides, each input node is connected to the output node by a weighted link. The weights represent the strength of the synaptic connections between neurons. Note that the human teaching-learning process also consists of altering the strength of such connections, based on a repeatedly produced stimulus. In the *perceptron*, the output node computes the weighted sum of inputs, including a term of influence, or *bias*, that serves to produce some value in the case all weights are null. Thus, a linear combination of input values is conducted. Subsequently, the output node makes use of a simple activation function, verifying the sign of the value to produce the final output. If the value is negative, then the output is -1, otherwise the output is +1. These values indicate the class of the instance being analyzed. Therefore, the *perceptron* learning process is the adaptation of weight values until an acceptable relation between input and output is obtained, according to what is observed in the instances of training[33]. Once trained, it is expected the ANN to be able to generalize the knowledge about the elements in question, so as to classify—correctly—future examples for which the classification is still unknown.

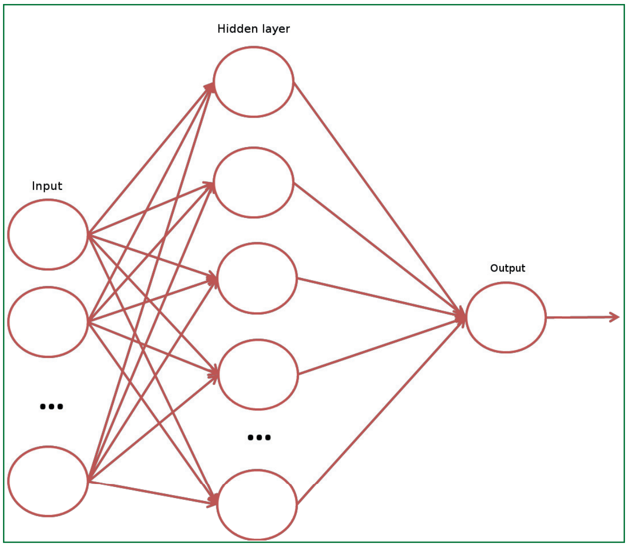
**Figure 1:**
The output node computes the sum $p_0 + p_1a_1 + p_2a_2 + \ldots + p_ka_k$ and check whether the result is negative or positive. Next, this node uses its simple activation function to output -1 our +1, respectively. The training process is the adjustment of the connection weights so that the output is according to what is expected regarding the training examples.




In order to allow modeling more complex relationships between input and output values—so as to, for instance, permit non linear decision boundaries or more than one decision boundary—there was a significant evolution from the *perceptron* to a more complete network architecture, the multilayer artificial neural network. In this model, an ANN can contain several intermediate layers, the hidden layers. Furthermore, it can use more complex activation functions, such as hyperbolic tangent functions and sigmoid functions[32]. It is also possible to include more than one output node. All these features combined provide more powerful and flexible ANNs.

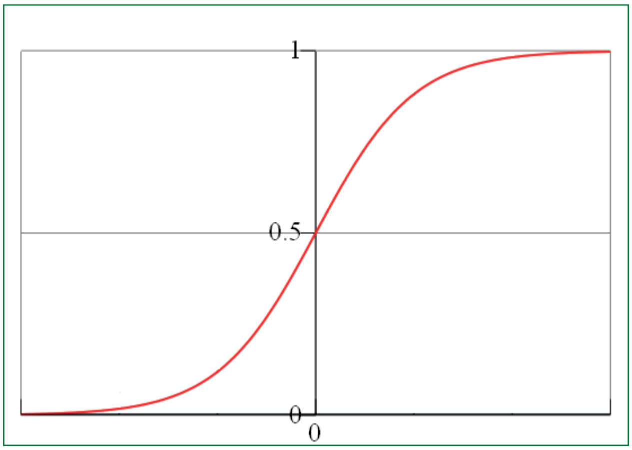
Another element that lends power to artificial neural networks is the possibility of more elaborate trainings such as the application of the back-propagation method in which the deviation between observed and expected outputs is used in a sophisticated formula of weight correction where alterations are applied in reverse direction, i.e., weights at layer $d$+1 are modified before weights at layer $d$[32]. Figure 2 shows an ANN with only one hidden layer, for the sake of image simplification.

**FIGURE 2:**
An example showing an artificial neural network containing a hidden layer. There can be as many hidden layers as needed and more than one output.




Another interesting characteristic of ANNs is the possibility to provide probability values as output, instead of just class values like positive and negative or yes and no[30, 31, 32]. For example, to perform the training of an ANN that will indicate—given someone's attributes such as weight, height, age, and the practice of physical activity—whether the risk of cardiac problems exists or not for a certain individual, such occurrences in previous patients must be provided to the ANN. However, it is very common in such scenarios to find individuals with exactly the same characteristics but different results, namely, despite both showing the same attribute values, one presents heart problems, while the other does not. In such cases, it makes much more sense to present the tendency of occurrence of an event than inform that it doubtlessly will occur. The idea is that although there are many individuals with identical characteristics but distinct results, the network will detect which of those possessing such attribute values will be more or less likely to present certain clinic outcome—such as a morbid cardiovascular event—based, for instance, in the frequency of a certain result in these individuals. To provide probability as output, it is common to use sigmoid functions, since they perform a mapping between output values and the corresponding values in the range [0, 1] that can be interpreted as probabilities[30,31,32]. Figure 3 exhibits a sigmoid function. One can notice in the figure that negative values are mapped to probabilities smaller than 0.5, while positive values correspond to probabilities superior or equal to 0.5. This happens because classifiers that exhibit probability normally conduct the training in such a way that the value 0.5 is used to decide to which class an instance belongs. However, although the values 0.6 and 0.9, for example, indicate the same class, the second value provides a greater degree of confidence.

**FIGURE 3:**
Sigmoid function. It is frequently used to map values computed by an artificial neural network to values in the range [0,1] that can be interpreted as probabilities.




Another advantage in the use of probability, concerning the ANNs, regards the perspective for the user of analyzing various cutoff values—not only the value 0.5—being able to verify the rates of misclassification that the model presents with respect to the training data in question. Thereat, it is possible to study the cost/benefit of using, for example, a higher cutoff value, thus losing some instances but, on the other hand, reaching a higher percentage of precision in the detected instances[30, 31, 32].

## ARTIFICIAL NEURAL NETWORKS: USES IN MEDICAL EDUCATION

Numerous studies have demonstrated the role of ANNs in medicine, from the student's education to the physician's practice (Table 2).

The use of new computer technologies in medical education has brought countless advantages to the process of acquiring skills[34]. In this perspective, the ANNs have been increasingly used in medical teaching, since they are a computer model extremely useful for solving complex clinical problems[35]. Moreover, positive effects in the students' teaching-learning process have been described, with higher capacity of informa-

**TABLE 2.**
**Summary of the Main Selected Articles.**

| Authors | Year | Contributions of the Artificial Neural Networks to Medical Teaching | Other Contributions of the Artificial Neural Networks to Medical Practice |
|---|---|---|---|
| Bergeron *et al.* | 1990 | **Building knowledge:** ANNs were used to build educational multimedia programs, offering a better understanding of concepts in the courses offered. | |
| Stevens and Lopo | 1994 | **Evaluation Process:** Simulations—based on immunology and infectology—were used to train ANNs to help identifying specific deficiencies in the teaching-learning process, mainly difficulties in differential diagnosis. | |
| Stevens *et al.* | 1996 | **Evaluation Process:** The use of ANNs trained to evaluate the solution of complex problems—in the field of infectious diseases—allowed to study the learning dynamics of a group of medicine undergraduates. | |
| Stevens and Najafi | 2003 | **Building knowledge:** Computational simulations were able to provide a better handling of immunology concepts. **Evaluation Process:** The ANNs were trained to judge a problem solution, helping to assess student performance. | |
| Olsson *et al.* | 2006 | | **Diagnostic Methods:** The interpretation of changes in the ST segment of the electrocardiogram, with the use of ANNs, showed 95% of sensibility and 88% of specificity, what may contribute to a better diagnosis and treatment of patients with acute coronary syndrome. |
| van Heerderen *Et al.* | 2008 | **Evaluation Process:** The ANNs were used to identify predictors of academic success among students of medicine through 99 input variables. This computer technique allowed the student's performance to be predicted with 100% accuracy. | |
| Oda *et al.* | 2009 | | **Diagnostic Methods:** ANNs showed useful in detecting pulmonary nodes in chest X-rays when compared to the isolated analysis of a radiologist. |
| Adjouadi *et al.* | 2010 | | **Diagnostic Models:** Computational strategy based on ANN diagnosed acute lymphocytic leukemia with 99.67% of sensitivity. |
| Mazurovsky *et al.* | 2010 | **Building knowledge:** A computer model—with the function of relating the image characteristics with the probability of error of breast cancer diagnosis made by a student in radiology through the analysis of a mammogram—has shown the ability to accurately predict the degree of difficulty in each case. | **Diagnostic Models:** The study results demonstrate the possibility of developing computer support systems to improve the accuracy in the diagnostic of mammary neoplasia detectable by mammograms. |
| Dey *et al.* (a) | 2011 | | **Diagnostic Models:** Cases of lobular carcinoma, benign neoplasms and ductal breast carcinoma were detected by fine needle aspiration biopsy and computation of data obtained on cytology, with the use of ANNs. |
| Dey *et al.* (b) | 2011 | | **Estimation of Prognostic:** ANN models were successfully used to predict the prognostic of chronic myeloid leukemia. |
| Barward *et al.* | 2012 | | **Diagnostic models:** After adequate training, computer models based on ANNs were able to correctly diagnose cases of pleural effusion of malignant origin. |
| Yuan *et al.* | 2012 | | **Estimation of Prognostics:** Applicability of the ANNs in predicting the answer of patients with colorectal metastatic cancer to chemotherapy—with sensitivity and specificity of 93% for both, considering the use of seven biomarkers. |
| Geimer | 2013 | | **Diagnostic Methods:** The use of algorithms based on ANNs showed more sensibility in the diagnosis of glaucoma, compared to ophthalmologists non specialized on the disease. |

*ANNs: artificial neural networks*

tion storage, systematic data analysis and the development of new approaches to solve each problem presented[35,36]. Thereat, medical education can be favored with a greater variety of knowledge and ways of learning, meeting the needs that the present imposes: A myriad of abilities the medical professional requires to act[15, 37].

ANNs have also been used in the students' evaluation process, when they're exposed to the simulation of a clinical case[38]. Another study suggested the opportunity of studying the dynamics of the learning process in clinical and laboratorial diagnosis, both individually and collectively[36,38,39].

Computer programs were developed using the logic of ANNs and have demonstrated the capacity to build several skills—like the proficiency in the solution of clinical problems—associated with the conveniences of both being portable, offering interactivity and improving learning with simulations and graphic resources[40, 41]. These programs offer an alternative to lab classes once they allow to simulate situations with variables of difficult handling or that cannot be altered jointly with others[40]. It should be noted also that the computer models that simulate neural functioning are gaining increased application in medicine, enhancing scientific research—helping to broad knowledge about countless morbid conditions—and furthering the development of new diagnostic methods as well as new approaches to prognostics[41,51]. Researches aimed at situations with bioethics implications[52]—including the process of decision making[53,54]—have also been conducted.

Such observations point to the necessity of changing medical curriculum and training students in these new technologies[24]. In fact, incorporating ANNs to medical education will only make sense and demonstrate applicability along with pedagogical change in educational institutions and a reflection on the act of teaching[55].

## FINAL CONSIDERATIONS

The ANN technique represents a multidisciplinary cooperation—involving the fields of neuroscience, mathematics, computer science, and statistics— being applied to various problems in different areas, including medicine. Its ability in recognizing patterns is widely applied in image recognition, spectral analysis, decision making in complex problems—linear and non linear—among other subjects.

Research targeting ANNs has enabled the development of high-performance computing—with networked processors assuming the role of neurons—with emphasis on its high processing capacity. Furthermore, the advancements in the cognitive computational area contribute to the building of "intelligent" machines, skilled in control and signal processing. It should not be expected a single machine to solve all problems. But each intelligent machine can acquire a specific application— notably, in this context, the application of ANNs in the field of medicine and the medicine teaching.

## REFERENCES

1. Siqueira-Batista R. Conhecimento e saúde: entre ciência e arte. In: Rego S, Palácios M. Comitês de ética em pesquisa: teoria e prática. Rio de Janeiro: Editora Fiocruz; 2012. p. 53-70.
2. Schramm FR. Existem boas razões para se temer a biotecnociência? Bioethikós 2010; 4:189-197.
3. Siqueira-Batista R, Maria da Silva L, Medeiros-Souza RR, Pires-do-Prado HJ, Aprigio-da-Silva C, Rôças G, Oliveira AL, Helayël-Neto JA. Nanociência e nanotecnologia como temáticas para discussão de ciência, tecnologia, sociedade e ambiente. Ciência e Educação (UNESP) 2010; 16:479-490.
4. Broeders IA. Robotics: The next step? Best Pract Res Clin Gastroenterol 2014;28(1):225-32.
5. Siqueira-Batista R. O nascimento da filosofia: uma peça em três atos. Lugar Comum (UFRJ) 2011; 33-34:215-225.
6. Nunes WV. Introdução às redes neurais artificiais. In: Esperidião-Antônio V. Neurociências: diálogos e interseções. Rio de Janeiro: Editora Rubio, 2012. p. 1-768.
7. Siqueira-batista R, Esperidião Antonio V, Medeiros-Souza RR, Alves Ferreira R, Gomes AP, Majeski-Colombo M, De Jesus VLB, Oliveira AL, Geller M, Batista RS, Helayël-Neto JA. Neurociências e educação: um tempo de encontro no espaço dos saberes. Rev Ciências Ideias 2010; 2(1):1-16.
8. Braga AP, Carvalho APLF, Ludermir TB. Redes Neurais Artificiais: teoria e aplicações. Rio de Janeiro: LTC; 2000.
9. Leondes CT. Neural Network Systems Techniques and Applications. California: Academic Press; 1998.
10. Patel VL, Shortliffe EH, Stefanelli M, Szolovits P, Berthold MR, Bellazzi R, Abu-Hanna A. The coming of age of artificial intelligence in medicine. Artific Intelligence Med 2009; 46(1):5-7.
11. Papik K, Molnar B, Schaefer R, Dombovari Z, Tulassay Z, Feher J. Application of neural networks in medicine: a review. Med Science Monitor 1998; 4(3):538-546.
12. Streba CT, Ionescu M, Gheonea DI, Sandulescu L, Ciurea T, Saftoiu A, Vere CC, Rogoveanu I. Contrast-enhanced ultrasonography parameters in neural network diagnosis of liver tumors. World J Gastroenterol. 2012;18(32):4427-34.
13. Brasil. Constituição da República Federativa do Brasil. Disponível em: <http://www.senado.gov.br/legislacao/const/con1988/CON1988_05.10.1988/CON1988.pdf> [Acesso em: 28 de fevereiro de 2012].

14. Cotta RMM, Campos AAO, Mendonça ET, Costa GD, Machado JC, Silva LS, Siqueira RL, Leão RT, Reis RS. Políticas de saúde: desenhos, modelos e paradigmas. Viçosa: Editora UFV; 2013.
15. Brasil. Resolução CNE/CES Nº 4, de 7 de novembro de 2001. Disponível em: http://portal.mec.gov.br/cne/arquivos/pdf/CES04.pdf. [Acesso em: 28 de fevereiro de 2012].
16. Siqueira-Batista R, Gomes AP, Albuquerque VS, Cavalcanti FOL, Cotta RMM. Educação e competências para o SUS: é possível pensar alternativas à(s) lógica(s) do capitalismo tardio? Ciên Saúde Coletiva 2013;18(1):159-170.
17. Freire P. Pedagogia do oprimido. 38.ed. São Paulo: Paz e Terra; 2004.
18. Gomes AP. Olhando o sistema de avaliação discente com os óculos da mudança: aprender a ver, aprender a avaliar. In: Moço ETSM, Falcão HBPT, Miranda JFA. Reflexões sobre as mudanças curriculares na área de saúde: ativando processos. .Rio de Janeiro: Publit; 2007. p. 13-37.
19. Freire P. Pedagogia da autonomia. Saberes necessários à prática educativa. São Paulo: Paz e Terra; 2003.
20. Nogueira MI. Trabalho em saúde e trabalho médico: especificidades e convergências. Rev Bras Educ Med 2012; 36(3): 414-422.
21. Acharya UR, Yu W. Data Mining Techniques in Medical Informatics. Open Med Inform J. 2010; 4: 21-22.
22. Meidani Z, Sadoughi F, Ahmadi M, Maleki MR, Zohoor A, Saddik B. National health information infrastructure model: a milestone for health information management education realignment. Telemed J E Health; 18(6):475-83.
23. Ramick DC. Data warehousing in disease management programs. J Healthc Inf Manag. 2001; 15(2):99-105.
24. Chen M, Safdar N, Nagy P. Should Medical Schools Incorporate Formal Training in Informatics? J Digital Imag 2011; 24(1):1-5.
25. Oden M, Mirabal Y, Epstein M, Richards-Kortum R. Engaging Undergraduates to Solve Global Health Challenges: A New Approach Based on Bioengineering Design. Ann Biomed Engineering 2010; 38(9):3031-3041.
26. Al-Shayea QK. Artificial Neural Networks in Medical Diagnosis. Int J Computer Science Issues 2011; 8(2):150-154.
27. Suebnukarn S, Haddawy P. A Bayesian approach to generating tutorial hints in a collaborative medical problem-based learning system. Artif Intell Med. 2006;38(1):5-24.
28. Oyana TJ, Achenie LE, Heo J. The new and computationally efficient MIL-SOM algorithm: potential benefits for visualization and analysis of a large-scale high-dimensional clinically acquired geographic data. Comput Math Methods Med. 2012;2012:683265. . Mitchell TM. Machine Learning. Singapore: McGraw-Hill; 1997.
29. Baldi P, Brunak S. Bioinformatics: The machine learning approach. 2nd edition. Massachusetts: The MIT Press; 2001.
30. Witten IH, Frank E. Data mining: Practical machine learning tools and techniques. 2nd edition. San Francisco: Morgan Kaufmann; 2005.
31. Tan PN, Steinbach M, Kumar V. Introduction to data mining. Boston: Addison-Wesley; 2006.
32. Rosenblatt F. The perceptron, a perceiving and recognizing automaton <Project Para>. Cornell Aeronautical Laboratory report. Buffalo, NY, 1957.
33. Abensur SI, Tamosauskas MRG. Tecnologia da Informação e Comunicação na Formação Docente em Saúde: Relato de Experiência. Rev Bras Edu Méd 2011; 35(1):102-107.
34. Stevens RH, Najafi K. Can artificial neural networks provide an "expert's" view of medical students performances on computer based simulations? Proceedings of the Annual Symposium on Computer Application in Medical Care 1992; 179-83.
35. Subbaiah RM1, Dey P, Nijhawan R. Artificial neural network in breast lesions from fine-needle aspiration cytology smear. Diagn Cytopathol 2014; 42(3):218-24.
36. Maranhão EA, Gomes AP, Siqueira-Batista R. O que mudou na educação médica a partir das Diretrizes Curriculares Nacionais: sob os olhares do Jano de Duas Faces. In: Streit DS, Barbosa Neto F, Lampert JB, Lemos JMC, Batista NA. 10 anos de Diretrizes Curriculares Nacionais. Rio de Janeiro: ABEM; 2012. p. 59-91.
37. Stevens RH, Lopo AC. Artificial neural network comparison of expert and novice problem-solving strategies. Proceedings of the Annual Symposium on Computer Application in Medical Care 1994; 64-68.
38. Van Heerden B, Aldrich C, du Plessis A. Predicting student performance using artificial neural network analysis. Med Educ 2008; 42(5):516-517.
39. Bergeron BP, Morse AN, Greenes RA. A generic neural network-based tutorial supervisor for computer aided instruction? Proceedings of the Annual Symposium on Computer Application in Medical Care 1990; 9:435-439.
40. Barwad A, Dey P, Susheilia S. Artificial neural network in diagnosis of metastatic carcinoma in effusion cytology. Cytometry Part B Clinical Cytometry 2012; 82(2):107-111.
41. Hu X, Cammann H, Meyer HA, Miller K, Jung K, Stephan C. Artificial neural networks and prostate cancer--tools for diagnosis and management. Nat Rev Urol 2013; 10(3):174-8.

42. Dey P, Logasundaram R, Joshi K. Artificial neural network in diagnosis of lobular carcinoma of breast in fine-needle aspiration cytology. Diagnostic Cytopathology; 2011.
43. Dey P, Lamba A, Kumari S, Marwaha N (b). Application of an artificial neural network in the prognosis of chronic myeloid leukemia. Anal Quant Cytol Histol 2011; 33(6):335-9.
44. Adjouadi M, Ayala M, Cabrerizo M, Zong N, Lizarraga G, Rossman M. Classification of leukemia blood samples using neural networks. Ann Biomed Engineering 2010; 38(4):1473-82.
45. Dybowski R, Gant V. Clinical applications of artificial neural networks. New York: Cambridge University Press; 2001.
46. Mazurowski MA, Baker JA, Barnhart HX, Tourassi GD. Individualized computer-aided education in mammography based on user modeling: concept and preliminary experiments. Med Phys 2010; 37(3):1152-60.
47. Geimer SA. Glaucoma diagnostics. Acta Ophthalmol 2013; 91(thesis1):1-32.
48. Stevens RH, Lopo AC, Wang P. Artificial neural networks can distinguish novice and expert strategies during complex problem solving. J Am Med Informatics Assoc 1996; 3(2):131-138.
49. Yuan Y, Tan CW, Shen H, Yu JK, Fang XF, Jiang WZ, Zheng S. Identification of the biomarkers for the prediction of efficacy in first-line chemotherapy of metastatic colorectal cancer patients using SELDI-TOF-MS and artificial neural networks. Hepatogastroenterology 2012; 5 (120): 2461-5.
50. Oda S, Awai K, Suzuki K, Yanaga Y, Funama Y, MacMahon H, Yamashita Y. Performance of radiologists in detection of small pulmonary nodules on chest radiographs: effect of rib suppression with a massive-training artificial neural network. AJR Am J Roentgenol 2009; 193(5):W397-402.
51. Olsson SE, Ohlsson M, Ohlin H, Dzaferagic S, Nilsson ML, Sandkull P, Edenbrandt L. Decision support for the initial triage of patients with acute coronary syndromes. Clin Physiol Funct Imaging 2006; 26(3):151-6.
52. Kim SH, Lee JM, Kim JH, Kim KG, Han JK, Lee KH, Park SH, Yi NJ, Suh KS, An SK, Kim YJ, Son KR, Lee HS, Choi BI. Appropriateness of a donor liver with respect to macrosteatosis: application of artificial neural networks to US images--initial experience. Radiology 2005; 234(3):793-803.
53. Siqueira-Batista R, Cerqueira FR. Computational support for decision making in clinical bioethics. In: X Congresso Brasileiro de Bioética, 2013, Florianópolis. Rev Bras Bioética 2013; 9(supl.): 202-203.
54. Siqueira-Batista R, Schramm FR. Bioética e neurociências: variações sobre o tema dos paradoxos da autonomia. In: Esperidião-Antônio V. Neurociências: diálogos e interseções. Rio de Janeiro: Editora Rubio, 2012, p. 473-487.
55. Barnett GO. Information technology and medical education. J Am Med Informatics Assoc 1995; 2(5):285-91.



## AUTHORS CONTRIBUTIONS

Rodrigo Siqueira-Batista designed with Fábio Ribeiro Cerqueira the structure of the present paper, and contributed equally in this work. Subsequently Rodrigo Roger Vitorino developed—under their supervision—the first version of it. Andréia Patrícia Gomes, Alcione de Paiva Oliveira, Ricardo dos Santos Ferreira, Vanderson Esperidião-Antonio e Luiz Alberto Santana undertook the final revision.


## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## CORRESPONDENCE


Rodrigo Siqueira-Batista
Universidade Federal de Viçosa
Campus de Viçosa
Departamento de Medicina e Enfermagem
Avenida Peter Henry Rolfs, s/n
Campus Universitário
Viçosa – MG
CEP: 36570-900
E-mail: rsbatista@ufv.br

Fábio Ribeiro Cerqueira
Universidade Federal de Viçosa
Campus de Viçosa
Departamento de Informática
Avenida Peter Henry Rolfs, s/n
Campus Universitário
Viçosa – MG
CEP: 36570-900
E-mail: frcerqueira@gmail.com