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The Significance of Artificial Neural Networks in Educational Research: A Summary of Research and Literature

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Abstract. Today based on the improvements in computer technologies, research aims at developing new ways of processing data. Some research focus on creating new instruments which imitate the biological data processing mechanisms of human beings. These kinds of research have paved the way for the development of artificial neural networks which can be regarded to be a superior tool for predictive analysis when compared to the traditional and more commonly applied predictive analysis tools. Today artificial neural networks have gained widespread applications in such disciplines as ecology, engineering and health. However, it can be alleged that they have been confined to limited application in educational research though they could be more functional and effective than other predictive analysis. This study aims at shedding light on the functionality and the role which artificial neural networks can fulfill in educational research by referring to the studies which were carried out through articial neural networks analysis.

Keywords: artificial neural networks, multilayer perceptron, single layer perceptron, input layer, hidden layer

Introduction

Artificial neural networks are data processing systems which simulate the data processing systems of the human beings (Elmas, 2003, p. 22). The idea of artificial neural networks has stemmed from imitating the functioning principles of human brain on the computer systems which compute with quantitative data and creating a mathematical model of biological neurons (Efe & Kaynak, 2000, p. 1). The first artificial neural network was created by the neurophysiologist Warren McCulloch and the mathamatician Walter Pitts based on the computing capacity of the human brain (Bishop, 2014, p. 9). The research on artificial neural networks accelerated after Frank Rosenblatt developed the artificial neural network system called perceptron in 1958 and then new systems followed it such as adaptive linear element (Adaptive linear element (Widrow & Hoff, 1960), Hopfield network (Hopfield, 1982), Kohonen network (Kohonen, 1982, 1984), Boltzmann machine (Ackley et al., 1985) and multi-layer feed-forward neural networks learned by backpropagation algorithm (Rumelhart et al., 1986; as cited in Lek & Guegan, 1999, p. 67). Modern research on artificial neural networks focus on developing new and more effective learning algorithms and creating networks which can respond to the models which can alter over time (Kriesel, 2007, pp. 21-22).

As mentioned before, artificial neural networks simulate the biological neurons in human brain and mathematical model of creating an artificial neuron is based on the biological model (Kohli et al.,, 2014, p. 745). Hanrahan(2011, p. 5) depicts the structure of a biological model as in the Figure 1;

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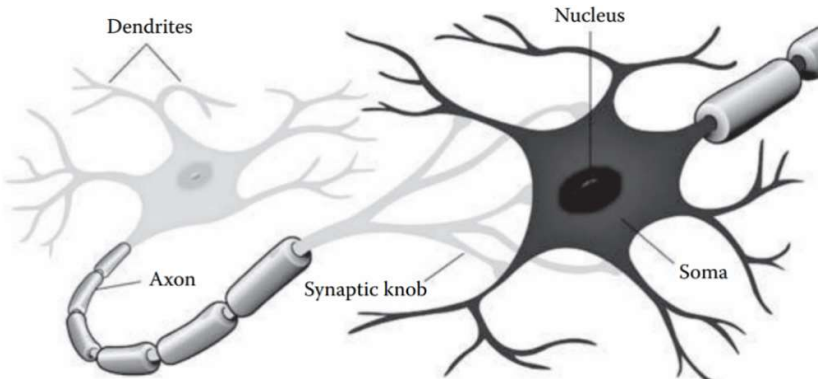

Figure 1. *The Structure of a Biological Neuron*

Note: Adapted from the book *Artificial neural networks in biological and environmental analysis*, by G. Hanrahan, 2011, p. 5. Copyright, 2011, by CRC Press.

In figure 1 soma depicts where the cell nucleus is located in the neuron and the dendrites are tree-like nerve fibres which receive signals from other neurons. Extending from the cell body is a single long fibre called the axon which branches into strands and substrands linking to many other neurons at the synapses (Yegnanarayana, 2005, p. 16). Signals are passed between neurons through connection links and input signals are transformed into output signals in the neurons (Fausett,1994, p. 3). In this regard, there is a kind of information exchange between the neurons and this exchange is illustrated in Figure 2 (Kriesel, 2007, p. 39);

Figure 2. *Data Processing of an Artificial Neuron*
Note: Adapted from the book *A brief introduction to neural networks* by D. Kriesel, 2007, p. 39. Copyright, 2007 by FAQ.

Data input refers to the data sets which are obtained from other neurons and artificial neurons are able to identify and learn associated patterns between input data sets and corresponding target values (Lek & Guegan, 1999, p. 66). While designing the system, the input data should be carefully selected based on the type of forecasting (Trifonov et al., 2017, p. 2). Propagation function in the artificial neuron transforms the output into an input (Kriesel, 2007, p. 39). Activation function is one of the main components of an artificial neural system and it is formed by weighting input links individually (Farizawani et al., 2020, p. 2). And finally output activation transforms the new activation into output for the other artificial neurons (Kriesel, 2007, p. 39). The artificial neural networks are composed of layers and they are divided into two categories in terms of the number of layers they contain: Single layer and multilayer artificial neural networks. A single layer network consists of only an input and an output layer as shown in Figure 3 (Haykin, 2009, p. 21);

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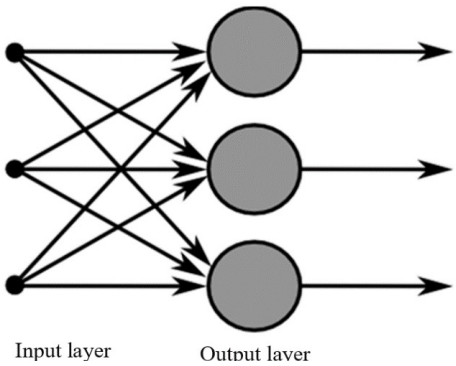

Figure 3. *An Example of a Single Layer Artificial Neural Network*

Note: Adapted fromthe book *Neural networks and learning machines* by S. Haykin, 2009, p. 21. Copyright Pearson Education Inc.

The data is received into the network through input layer and then after it is proccesed, it is transmitted via the output layer (Kantardzic, 2011, p. 205). Single layer artificial neural networks can be functional in solving simple problems but to solve more complex problems the net could be transformed into a multi layer form. In this case, apart from the input and output layers, at least one hidden layer which increases the effectiveness and storing capacity of the model is added to the net (Mijwel, 2017, s. 2). A multilayer artificial neural network can be illustrated as in Figure 4 (Gurney, 2004, p. 98);

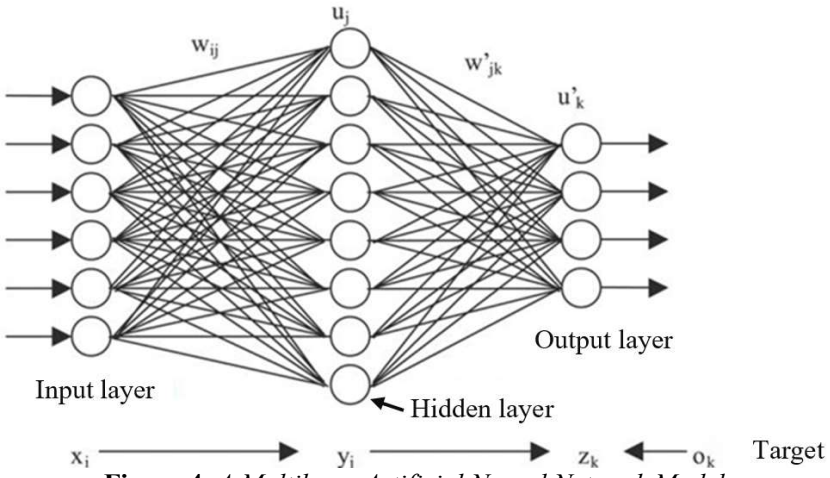

Figure 4. *A Multilayer Artificial Neural Network Model*

Note:Adapted from the book *An introduction to neural networks* by K. Gurney, 2004, p. 98. Copyright by Taylor & Francis e-Library.

The last compoent of an aritificial neural netwok is the learning algorithm. Once the number of all layers in the neural network and the number of neurons in them are determined, the weights of the connections between neurons should be set in such a way in order to minimize the error in the predictions made by the neural network. This is the role of the training algorithm (Trifonov et al., 2017, p. 5). Apart from its components, an artificial neural network has some characteristics which make it an effective analysis tool and these characteristics are summarized in Figure 5 (Kumar & Sharma, 2014, p. 145);

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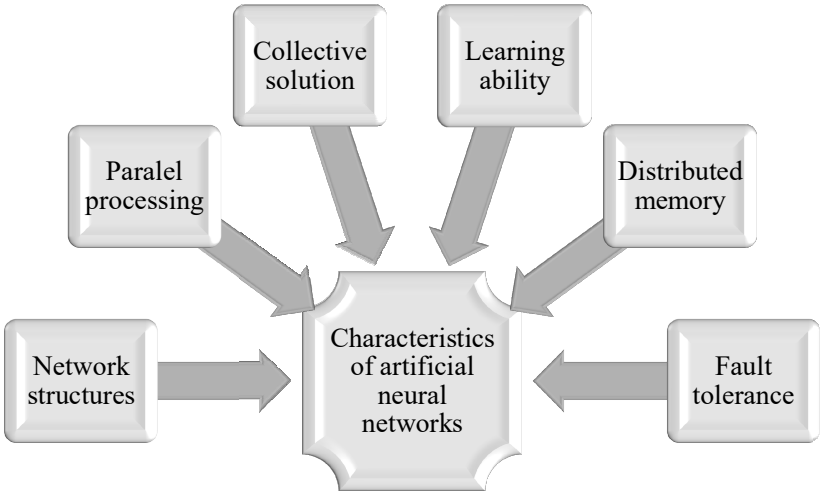

Figure 5. *The Basic Characteristics of an Artificial Neural Network*

Note:Adapted from the article *Artificial neural networks-a study* by Kumar & Sharma, 2014, p. 145.

The artificial neural networks simulate the data processing of biological neurons and it is comprised of interconnected processing elements called nodes or neurons which cooperate so as to produce an output function (Hanrahan, 2011, p. 6). The artificial neural networks allow forecasting without intimate knowledge about the processes (Abrahart et al., 2014, p. 1). The output of a neural network relies on the functional cooperation of the individual neurons within the network, where processing of information is characteristically done in parallel rather than sequentially as in earlier binary computers (Hanrahan, 2011, p. 6). This is one of the major differences between traditional computer systems and artificial neural networks (Elmas, 2003, p. 24). The basic principle which lies behind the construction of artificial neural networks is that they imitate the functioning principles of the biological neurons (Lancashire et al., 2009, p. 316).

A neural network model is the branch of artificial intelligence and it teaches the system to execute task, instead of programming computational system to do definite tasks (Saravanan & Sasithra, 2014, p. 11) . Artificial neural networks have applications in a lot of disciplines and this results from the advantages and aplicability of artificial neural networks. The advantages of the artificial neural networks can be summarized as follows (Kumar & Sharma, 2014, p. 146);

- Adaptive learning: A neural network has the dexterity to learn the ways tasks are carried out.
- Self-organisation: A neural network can create its own representation of the information it obtains during learning process.
- Real time operation: In a neural network, computations could be fulfiled in parallel.
- Pattern recognition: Pattern recognition is regarded to be an effective way for data security. Neural networks have the ability to learn to recognize the patterns in the data sets.
- Learning capacity: A neural network system is developed by learning rather than programming. Neural networks teach themselves the patterns in the data sets and this leads to freedom of the analyst for more interesting work.
- Flexibility: Neural networks are effective in adapting to changing environment. It may take some time for neural networks to learn an abrupt massive change but they are effective in adjusting to the constantly changes in information.
- Informative models: Neural networks can set up informative models in cases where traditional approaches fail. As neural networks can cope with very complex interactions, they can easily model data which is too hard to model with conventional methods such as inferential statistics or programming logic.

- Performance: For most of the problems, performance of neural networks is better than the corresponding methods. This results from the fact that neural networks can establish models which are more complex in the structure of the data in a considerably less time.

All in all, as a tool for artificial intelligence, artificial neural networks can serve as a more efective tool for the resolution of educational problems which are generally complex in nature. It has many applications in different disciplines such as computer science, data mining, medicine, business and aviation (Kohli et al., 2014, pp. 748-749).Artificial neural networks can serve as an effective analysis tool also in educational research although it has not been able to obtain the attention which it deserves. The fact that artificial neural network analysis is installed in the SPSS packet program which is one of the most commonly utilized analysis packet program for educational research is another advantage which makes the artificial neural networks analysis more applicable and available.

The Purpose of the Study

The core purpose of this study is to help establish a clear understanding for the significance and functionality which artificial neural networks can have in educational research and to draw some directions for future research in education through artificial neural networks. The main objective is to enable or at least help artificial neural networks as an effective analysis tool gain popularity and widespread application in the realm of educational research. In this regard, this study aims at shedding light on the areas where artificial neural networks can be applied in educational research. The study also tries to attract the attention towards the functionality of artificial neural networks in educational research and set up a vision for future research. In this core context, the following research problems constituted the scope of this study;

- In which domain of analysis in educational research can artificial neural networks be functional?
- What are the superiorities of artificial neural networks over the other analysis tools for the same domains?
- Which future applications can be drawn out of in the light of the current educational research carried out through artificial neural networks?

Method

Under this heading, the reseach model, data collection procedures and data analysis techniques are summarized.

Research Model

A qualitative research model was applied for the execution of this study as it provides an in-depth, intricate and detailed understanding of meanings, actions, non-observable as well as observable phenomena (Cohen et al., 2018, p. 288).Qualitative research is a research strategy which usually focuses on words rather than quantification in the collection and analysis of data (Bryman, 2012, p. 380). As the main goal of this study is to reveal areas of educational research and analysis for artificial neural networks, a qulaitative approach was regarded to be the most appropritate model.

Research Design

This study is in the form of a systematic review and qualitative analysis is also an effective tool for reviews (Cohen et al., 2018, p. 288; Dixon-Woods et al., 2001, p. 125). During the review process, document analysis was determined to be the most applicable research design as it is an effective verbal way of collecting and summarizing data in qualitative research model (Lodico et al., 2006, p. 5). Document analysis is a method which allows the researcher to have an understanding for such components as the motivation for the creation of the document, the use and the target audience (Costantino, 2008, p. 403). This study tries to uncover in which realms of educational research the artificial neural networks could be functional and in this regard document analysis was determined to be most applicable design for the study. The document analysis also allows the researcher to decide what type of documents to review by taking the research questions into account (Costantino, 2008, p. 403). In this regard, it permits the researcher to restrict the scope of the documents to be reviewed to the research articles created in the realm of educational research fulfilled through artificial neural networks.

Data Collection

The data was collected through document analysis with a literature review point of view focusing on the research articles in the realm of education carried out via the artificial neural networks. Leavy (2017, p. 56) defines literature review as “both a process and product”. Literature review can

provide deep understanding for the topics of interest that are both methodological and substantive (Gill & Johnson, 2002, p. 25). In this study, methodological review which is a specialized type of integrative review in which the relative methodological strength of various studies are compared and evaluated and how methodologies account for different results is revealed (Neuman, 2014, p. 127). As this study aims at proving the relative strenght of artificial neural networks and how functional they can be in educational research, sample research articles fulfilled through artificial neural networks from the realm of education were delved.

Data Analysis

So as to analyze the documents and literature, the content analysis method was utilized. Content analysis is an approach to the analysis of documents and texts (Bryman, 2012, p. 289). Content analysis consists of various techniques devised to discover and describe qualitative verbal, written, and multimedia materials in a systematic and objective way (Crano et al., 2015, p. 303). The content analysis is carried out in three phases; skimming (superficial examination), reading (thorough examination), and interpretation (Bowen, 2009, p. 29).

In this study, qualitative reliability was established through delicate and comprehensive literature review. Also the articles studied were carefully selected. In qualitative research, the emphasis is not on the generalizability of the results, however it is regarded that the results can be useful for the group or the research domain (Cohen et al., 2018, p. 319). Because it is regarded that the results can be transferred to the similar situations. In this context, the term “transferability” rather than “genaralizability” is preferred in qualitative research (Bryman, 2012, p. 390). To ensure transferability in this study, the research articles studied were selected carefully so as to address the problems in the educational domain. Also the nature of the analysis fulfilled in the articles was taken into account in terms of its applicability and functionality in educational realm.

Findings

The findings of this study aim at verifying the effectiveness and efficiency of artificial neural networks in comparison and contrast to its counterpart statistical analysis tools applied for prediction and classification. In this context, the functionality of artificial neural networks are discussed taking their advantages over the conventional statistical instruments for prediction and classification. For the discussion, the results of some research in the realm of education has been taken as basis and comparative studies were also referred to.

Artificial neural networks can constitute an effective alternative for regression analysis which is widely applied in educational research. Pektaş (2013, p. 149) alleges that when the same data sets are analyzed through articial neural networks instead of regression analysis, artificial neural networks provide a more robust predictive power. He puts forward that through the predictive analysis fulfilled by artificial neural networks, it is possible to get a higher determination coefficient, which is a key component of predictive analysis, than the regression analysis. Apart from predictive analysis, artificial neural networks are also functional and effective in classification analysis (Kohli et al., 2014, p. 745). Multilayer artificial neural networks are more popular and more commonly utilized in research (Witten & Frank, 2005, p. 233) and the fundamental reason for that is its efficiency in coping highly dimensional complex datasets (Lancashire et al.,, 2009, p. 316). For predictive analysis, artificial neural networks analysis can constitute an effective alternative for regression analysis.

Pavlin-Bernardić et al., (2016, p. 49) allege that although artificial neural networks are functional in prediction and classification analyses, their application in the area of educational psychology is still relatively restricted. To be able to prove the effectiveness and efficiency of artificial neural networks they carried out a research for predicting the giftedness of the children. The research was carried out on a sample of 221 fourth grade students. They tested the accuracy of hyperbolic tangent multilayer perceptron and they found out that it was %100 effective in predicting non-gifted students and %75 effective in predicting gifted students in the sample. They concluded that artificial neural networks analysis is an effective tool for predictive analysis. The finding of the research could be regarded as an evidence for the efficiency and effectiveness of artificial neural networks analysis for predictive analysis in the realm of education.

Everson et al., (1994, p. 2) carried out a research to compare and contrast artificial neural networks with corresponding traditional statistical analysis such as multiple regression and discriminant function analysis for making classification or placement decisions in schools and

colleges. They compared the classification rates of multiple regression and discriminant analysis with artificial neural networks through the measures of arithmetic ability, high school achievement, test anxiety and gender. The analysis was carried out on the whole sapmle as well as subgroups as gender and the analyses were based on the measurements of algebra proficiency, using both cognitive and non-cognitive variables. In their research, they found out that artificial neural networks performed much better than the linear statistical models in predicting for example the algebra proficiency of females. They concluded that artificial neural networks are much more effective than the linear models of prediction and classification analysis.

Zacharis (2016, p. 17) puts forward that the application of artificial intelligence in education permits instructors to analyze data obtained from university servers, identify patterns of student behaviors and determine interventions for struggling students. In the study implemented on a sample of 265 students, he aimed at determining the effectiveness of artificial neural networks in predicting student achievement, depending on the data obtained from students' online activities in Web-based blended learning course. In the study, a multilayer perceptron neural network was trained to predict students' dexterity to successfully pass the course. It was found out that the classification accuracy rate was 98.3% in classifying the students into the success and failure categories determined beforehand. In the study, a literature review was also carried out to discover the strenght of artificial neural networks over the other prediction and classification algorithms and it was concluded that artificial neural networks outperformed all other classifiers.

Jain et al., (1996, p. 31) put forward some reasons for application of artificial neural networks for prediction and classification analysis: Massive parallelism, distributed representation and computation, learning capacity, generalization ability, adaptivity, inherent contextual information processing, fault tolerance and low energy consumption. Particularly learning and adaptive capacity of the artificial neural networks make them effective and efficent tools for prediction and classification.

Lau et al., (2019, p. 1) assert that traditional statistical analysis fall short of providing accurate predictions for the quality of education at universities. Thus, they have applied artificial neural networks in their research which they carried out on a sample of 1.000 students for predicting the performance of the universities. In the research, it was found out that artificial neural networks ensured a prediction accuracy of %84.8 which they regard as a quite high prediction veracity. This rate can be regarded as the proof of the efficiency of artificial neural networks for estimation.

Karamouzis and Vrettos (2008, p. 1) assert that they regard artificial neural networks as a functional instrument for prediction and in their reseacrh they aimed at predicting student outcomes through artificial neural netwoks. They carried out their research on 1.407 student profiles. The results were noteworthy for verifying the effectiveness of artificial neural networks for prediction as the model was able to predict 142 out of 172 successful graduates (%86.04) and 633 out of 928 unsuccessful graduates (%68.21). This finding could be a proof four our hypotheses that artificial neural networks are more effective than conventional statistical analysis tools for estimation.

In her research Siri (2015, p. 225) proposes that artificial neural networks are an effective tool for designing educational interventions for students who have a risk of dropout. In her research, based on a sample of 810 students, she aimed at predicting the dropout rates of the students at universities based on such variables as high school diploma grade and admission scores. She grouped the students in different categories based on different variables and artificial neural networks achieved unbelievable accuracy rates for each group; %84 for group 1, %81 for group 2. The findings can be taken as the proof for the effectiveness of artifificial neural networks as a predictive analysis tool.

In another research, fulfilled through the use of artificial neural networks Binh and Duy (2017, p. 6) aimed at predicting student performance based on learning styles. Studying on 316 undergraduate students, in their research they found out remarkable relationship between learning styles and student performance. They have utilized a multilayer perceptron in their research and they concluded it could be functional in predictive anaylsis and increasing the number of participants in the sample could add to the effectiveness of the model. In the same way, Usman and Adenubi (2013, p. 61) made use of artificial neural networks to predict the student academic performance before thay graduate. They carried out their reseacrh on 30 randomly selected university students. They found out that artificial neural networks were able to provide a almost perfect estimation with a rate of %92.7 accuracy. In their research, Kalejaye et al., (2015, p. 25) focusing on the use of artificial neural network for estimating students' academic performance in a university system based on the previous data sets, they

found out that the model set up via artificial neural networks was able to predict the student performance with an accuracy rate of %91.7. Adewale et al., (2018, p. 1) educational administrators and policy makers need an effective tool to predict student performance and they allege that artificial neural networks has the capacity to meet this demand. To prove this, they carried out a research with a sample of 120 students from different secondary schools and they found out that artificial neural networks achieved an accuracy rate of over %80 in most of the schools. The findings of all these researches could be regarded as an evidence of the effectiveness and efficiency of artificial neural networks for estimating the student performance.

Apart from predicting student performance, artificial neural networks can also fulfill some other important functions in education. Valko and Osadchyi (2020, p. 5) put forward that artificial neural networks can also be utilized to individualize education. They allege that artificial neural networks can be an effective tool to adjust the education to meet the individual learning needs of the students. As the individulization of the teaching and learning processes is an integral part of improving educational quality, it can be asserted that artificial neural networks can play an important role in the establishing individualized educational program for curriculums.

Conclusion

The research papers which were scrutinized in this study show the functionality of artificial neural networks in educational realm. The artificial neural networks with the predictive accuracy which they provide can be an efficient tool both for estimation and classification research in education. Especially the prediction about student performance can serve as a healthy basis for educational institutions during the admission procedures. In this regard, healthy estimation accuracy can help plan the educational programs and procedures more efficiently and effectively. As it was mentioned in the study, artificial neural networks perform better than their counterpart statistical analysis tools in terms of predictive accuracy. In this context, artificial neural networks should be considered as alternatives to the conventional statistical models utilized for classification and prediction in the realm of educational research. It can esaily be alleged that the use of artificial neural networks has been confined to a very limited number of educational studies hitherto although the efficiency and accuracy which they ensure for the researchers. Future research can contribute to artificial neural networks to gain importance and widespread use in educational research.

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