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Simulation of Improved Academic Achievement for a Mathematical Topic Using Neural Networks Modeling

Saeed A. Al-Ghamdi
Electrical Engineering Department, Faculty of Engineering, Al-Baha University, Al-Baha, Kingdom of Saudi Arabia.

Abdel Aziz M. Al-Bassiouni
Telecommunication & Technology Company
Cairo, Egypt.

Hassan M. H. Mustafa
Computer Engineering Department, Faculty of Engineering, Al-Baha University, Al-Baha, Kingdom of Saudi Arabia On leave from Banha University Egypt.

Ayoub Al-Hamadi
Institute for Information and Communication Technology, Otto-von-Guericke-University Magdeburg, Germany.

Abstract— This paper is inspired by the simulation of Artificial Neural Networks (ANNs) applied recently for evaluation of phonics methodology to teach the children "how to read?" Nevertheless, in this paper, a novel approach is presented aiming to improve the academic achievement in learning children as an adopted mathematical topic namely long division problem. That's by comparative study of practical application results at educational field (a children classroom); for two computer aided learning (CAL) packages versus classical learning (case study). Presented study highly recommends the novel application of interdisciplinary teaching trends as a measure for learning performance evaluation. It is based on ANNs modeling, memory association, behaviorism, and individual's learning styles. Interestingly, observed and obtained practical findings after the field application, proved the superiority of the package associated with teacher's voice over both without voice, and classical learning / teaching as well.

Keywords-Artificial Neural Networks; Learning Performance Evaluation; Computer Aided Learning; Long Division Process; Associative Memory.

I.INTRODUCTION

The field of learning sciences is represented by a growing community conceiving knowledge associated with educational system performance as well as the assessment of technology-mediated learning processes. Therefore, a recent evolutionary trend has been adopted by educationalists as well as learners due to rapid technological and social changes. Therefore, they are facing increasingly challenges which arise in this time considering modifications of educational field applications.

This research work is mainly motivated by what has been announced in U.S. as referred to the WHITE HOUSE REPORT in 1989. Therein, it has been considered the decade (1990-2000) as Decade of the brain [1]. Moreover, neural network theorists as well as neurobiologists and educationalists have focused their attention on making interdisciplinary contributions to investigate essential brain functions (learning and memory). Recently, Artificial Neural Networks (ANN) paradigms combined with neuroscience have been integrated as an interdisciplinary research direction.

That's to select optimal methodology for solving critical issue of children teaching/learning "how to read?" This research direction has been adopted by the great debate of children reading issue as presented at [2]. Where a group of researchers at fields of psychology and linguistic have been continuously cooperating in searching for optimal methodology which are supported by field results. Nevertheless, during last decade, phonics methodology is replaced –at many schools in U.S. by other guided reading methods performed by literature based activities [3]. Recently obtained promising field results as given by [4] have supported the optimality of phonics methodology in solving the children issue “how to read?” [5][6].

This paper is inspired by optimal adopted approach for improving teaching/ learning performance of a mathematical topic to children of about 11 years age. Herein, the suggested mathematical topic to teach children an algorithmic process to perform long division problem, specifically for two arbitrary integers numbers chosen in a random manner (each composed of some number of digits). In more detail, adopted principal algorithm for applied Computer Aided Learning (CAL) package consisted of five steps follows. Divide, Multiply, Subtract, Bring Down, and repeat (if necessary) [7][8]. The overview concerned with the effect of information technology computer (ITC) on mathematical education, refer to [9][10][11].

The rest of the paper is organized as follows. In section II, two motivation folds of this piece of research are given in subsections A and B. A basic interactive educational model is presented along with its generalized Artificial Neural Networks (ANNs) model (the block diagram) are presented at section III. In section IV, detailed illustration of adopted mathematical topic (long division problem) is given along with a simplified macro level flowchart for algorithmic steps to solve adopted problem. In the fifth section, two subsections (A and B) introduced practical results obtained in the case study, and simulation results, respectively. Some interesting conclusions in addition to suggestions for future work are presented in the section VI. Finally, two Appendices (A&B) are attached by the end of this work. One of appendices considers the heterogeneous Associative Memory Equations; however the other presents Supervising Learning Algorithm for various Learning Rate Values η.

II.MOTIVATION

During the nineteenth of last century, educationalists have adopted Computers and Information technology in order to perform deep changes in mathematics [10][11]. In this context, it is worthy to remember two of announced conclusive findings by Horgan and Aragón [12][13]. Respectively, these findings are as follows. “Computers are transforming the way mathematicians discover, prove and communicate ideas”[12]. And “Computers and computation have changed the entire modern world, but their effects in the fields of sciences and engineering have been especially deep” [13]. Furthermore, applied mathematics has become more and more computationally oriented and accordingly, the mathematical application software packages have been encouraged for using in physics, chemistry, and different branches of engineering [14][15]. Interestingly, the presented research approach is well supported by some published e-learning management reports and published works [16][17][18].

The motivation of this work has two folds as given in the following subsections (A and B). Firstly, the motivational fold concerned with ANN modeling paradigms relevant to educational applications in practice (at classrooms). However, the second motivational fold considers reforming of pedagogical approach based on computational algorithms and information technology, over the last few decades that resulted in rapid improvement of teaching mathematical methodologies [19].

A. First Motivational Fold

The overwhelming majority of neuroscientists have adopted the concept which suggests that huge number of neurons in addition to their synaptic interconnections constituting the central nervous system with its synaptic connectivity performing dominant roles for learning processes in mammals beside humans [20]. More specifically, this motivation is supported by what revealed by National Institutes of Health (NIH) in U.S. that children in elementary school, may be qualified to learn “basic building blocks” of cognition and that after about 11 years of age, children take these building blocks and use them [21][22]. The extremely composite biological structure of human brain results in everyday behavioral learning brain functions. At the educational field, it is observed that learning process performed by the human brain is affected by the simple neuronal performance mechanism [23]. In this context, neurological researchers have recently revealed their findings about increasingly common and sophisticated role of Artificial Neural Networks (ANNs). Mainly, this role has been applied for systematic and realistic modeling of essential brain functions (learning and memory) [24]. Accordingly, neural network theorists as well as neurobiologists and educationalists have focused their attention on making interdisciplinary contributions to investigate the observed educational phenomena associated with brain functional performance such as optimality of learning processes [25][26].

B. Second Motivational Fold

This research work is motivated by what announced in U.S. that mathematics education has gained significant momentum as a national priority and important focus of school reform (National Mathematics Advisory Panel, 2008) [25]. Additionally, the work is originated by pedagogical approach for evaluation of mathematical education performance. At the end of year 2012, it has been announced that a range of recording methods was documented, many of which seemed to be adaptations of mental and sensory methods of computation [28][29]. Students who used alternative methods tended to be less successful than students who used traditional algorithms. Therein, results suggested that there is a merit in conducting further research into the effects of using alternative written computational methods upon student’s learning of mathematics. More specifically, when applying the division algorithm, students frequently made number fact errors in multiplication or subtraction [29], therein stated that: “Division methods and errors associated with alternative methods”. Moreover, it is a worthy notice: presented the teaching methodologies associated with division errors which are likely similar to the adopted mathematical topic therein [30]. Both were generally related to attempts to use material based models such as allocating marks in boxes in the lower grades, and guess and check multiplication or alternative splitting strategies in the higher grades. A relatively high proportion of students who did not use the standard algorithm for division relied upon diagram based methods recommended by Van de Walle et al. (2010) for double-digit by single-digit multiplication [30][31].

III.INTERACTIVE LEARNING/TEACHING MODEL

From neurophysiologic point of view, generally practical learning process performance utilises two essential cognitive functions. Both are essentially required in performing efficient learning/teaching interactive process in accordance with behaviourism paradigm as follows [32][33][34].

Firstly, pattern classification/recognition functions based on visual/audible interactive signals are stimulated by CAL packages. Secondly, associative memory function is used which is originally based on classical conditioning motivated by Hebbian learning rule. Referring to Figure 1, it illustrates a general view of a teaching model qualified to perform simulation of above mentioned brain functions. Inputs to the neural network teaching model are provided by environmental stimuli (unsupervised learning). However, correction signal(s) in the case of learning with a teacher given by output response(s) of the model that evaluated by either the environmental conditions (unsupervised learning) or by supervision of a teacher. Furthermore, the teacher plays a role in improving the input data (stimulating learning pattern) by reducing the noise and redundancy of model pattern input. That is in accordance with tutor's experience while performing either conventional (classical) learning or CAL. Consequently, he provides the model with clear data by maximizing its signal to noise ratio [35]. Conversely, in the case of unsupervised/self-organized learning, which is based upon Hebbian rule [36], it is mathematically formulated by equation (7). For more details about mathematical formulation describing a memory association between auditory and visual signals, please refer to [5].

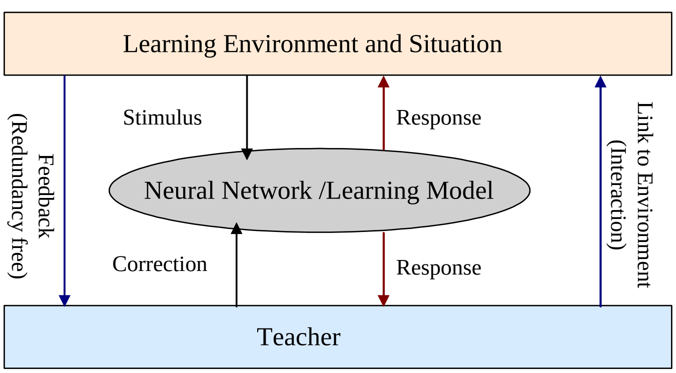

Figure 1. Simplified view for interactive educational process.

The presented model given in Figure 2 generally simulates two diverse learning paradigms. It presents realistically both paradigms: by interactive learning/ teaching process, as well as other self organized (autonomous) learning. By some details, firstly is concerned with classical (supervised by a tutor) learning observed in our classrooms (face to face tutoring). Accordingly, this paradigm proceeds interactively via bidirectional communication process between a teacher and his learners (supervised learning) [36] [37]. However, the second other learning paradigm performs self-organized (autonomously unsupervised) tutoring process [37]. Furthermore, detailed equations concerned with the mathematical formulation describing heterogeneous associative memory between auditory and visual pattern signals are introduced at Appendix I.

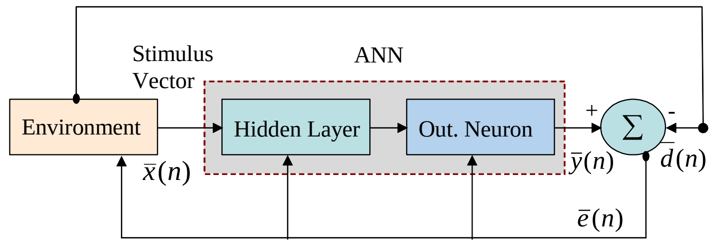

Figure 2. Generalized ANN block diagram simulating two diverse learning paradigms adapted from [19].

Referring to above Figure 2; the error vector $\bar{e}(n)$ at any time instant (n) observed during learning processes is given by:

$$\bar{e}(n) = \bar{y}(n) - \bar{d}(n) \tag{1}$$

where $\bar{e}(n)$ is the error correcting signal which is controlling adaptively the learning process, and $\bar{y}(n)$ is the output signal of the model. $\bar{d}(n)$ is the desired numeric value(s). Moreover, the following four equations are deduced:

$$V_k(n) = X_j(n) W_{kj}^T(n) \tag{2}$$

$$Y_k(n) = \varphi(V_k(n)) = (1 - e^{-\lambda V_k(n)})/(1 + e^{-\lambda V_k(n)}) \tag{3}$$

$$e_k(n) = |d_k(n) - y_k(n)| \tag{4}$$

$$W_{kj}(n+1) = W_{kj}(n) + \Delta W_{kj}(n) \tag{5}$$

where X is input vector and W is the weight vector. φ is the activation function. Y is the output. e_k is the error value and d_k is the desired output. Note that $\Delta W_{kj}(n)$ is the dynamical change of weight vector value. Above four equations are commonly applied for both learning paradigms: supervised (interactive learning with a tutor), and unsupervised (learning though student's self-study). The dynamical changes of weight vector value specifically for supervised phase is given by:

$$\Delta W_{kj}(n) = \eta e_k(n) X_j(n) \tag{6}$$

where η is the learning rate value during the learning process for both learning paradigms. However, for unsupervised paradigm, dynamical change of weight vector value is given by:

$$\Delta W_{kj}(n) = \eta Y_k(n) X_j(n) \tag{7}$$

Noting that $e_k(n)$ in (6) is substituted by $y_k(n)$ at any arbitrary time instant (n) during the learning process.

IV.ADOPTED MATHEMATICAL TOPIC

The teaching of long division has been announced to be the focus of heated arguments in world of mathematical education [7]. Some researchers claim it is too difficult and the children don't understand it, but rather perform it mechanically [7][8]. In Figure 3, a simplified macro level flowchart describing briefly basic algorithmic steps are presented for the mathematical topic of long division process. These are: Divide, Multiply, Subtract, Bring Down, and repeat (if necessary) [7]. Furthermore, this algorithm considered by two suggested CAL packages (with and without teacher's voice).

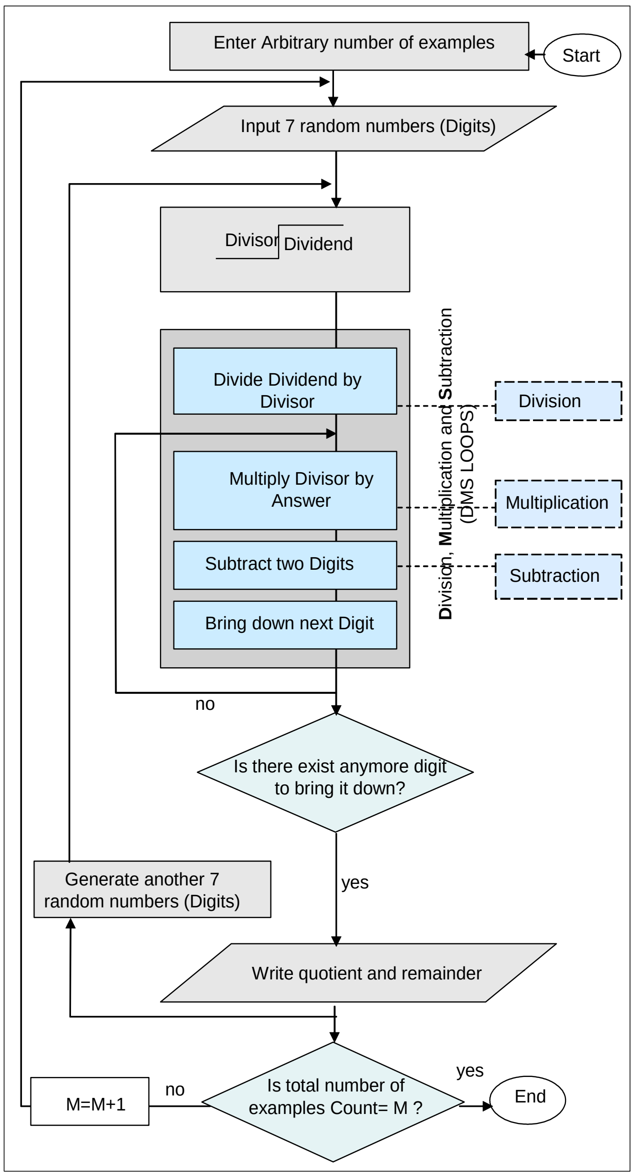

Figure 3. A simplified illustrative flowchart at the macro level. It describes in brief algorithmic steps for the suggested CAL package.

V.RESULTS

The results obtained after performing practical experimental work in classroom (case study) is shown in the subsection A. Additionally, in the subsection B., realistic simulation results are introduced. Interestingly, it is clear that both obtained results (practical and simulation) are well in agreement and supporting each other.

Practical Case Study Results

A learning style is a relatively stable and consistent set of strategies that an individual prefers to use when engaged in learning [38][39]. Herein, our practical application (case study) adopts one of these strategies namely acquiring learning information through two sensory organs (student eyes and ears). In other words, seeing and hearing (visual and audible) interactive signals are acquired by student's sensory organs either through his teacher or considering CAL packages (with or without teacher's voice)[40][41]. Practically, children are classified in three groups according to their diverse learning styles (preferences), each group composed of 15 children.

The two tables (Table I. & Table II.) illustrates the obtained practical results after performing three different learning experiments. In Table I, illustrated results are classified in accordance with different student's learning styles following three teaching methodologies. Firstly, the classical learning style is carried out by students-teacher interactive in the classroom. Secondly, learning is taken place using a suggested software learning package without teacher's voice association. The last experiment is carried out using CAL package that is associated with teacher's voice. This table gives children's achievements (obtained marks) in each group with maximum marks considered as 100. The statistical analysis of all three experimental marking results is given in details (see. Table II).

TABLE I. COMPARATIVE ACHIEVEMENTS PERFORMANCE

Classical Learning	35	43	29	50	37	17	10	60	20	48	15	55	40	8	20
CAL without Voice	39	29	52	60	50	68	62	30	55	42	40	59	48	70	2
CAL with Voice	65	70	50	75	45	50	62	90	85	50	80	90	58	55	60

TABLE II. ILLUSTRATES STATISTICAL ANALYSIS OF ABOVE OBTAINED CHILDREN'S ACADEMIC ACHEIVEMENT

Teaching Methodology	Children's average Achievement score (M)	Variance σ	Standard deviation $\sqrt{\sigma}$	Coefficient of variation $\rho = \sqrt{\sigma}$ / M	Improvement of teaching Quality
Classical	32.46	265.32	16.28	0.50	-
CAL (without tutor's voice)	46.80	297.49	17.24	0.36	44.1%
CAL (with tutor's voice)	64.33	283.42	16.83	0.26	98.2%

The suggested ANN model adapted from realistic learning simulation model given at [6] with considering various learning rate values. It is worthy to note that learning rate value associated to CAL with teacher's voice proved to be higher than CAL without voice. Simulation curves at Fig. 2 illustrate the statistical comparison for two learning processes with two different learning rates. The lower learning rate (η = 0.1) may be relevant for simulating classical learning process. However, higher learning rate (η = 0.5) could be analogously considered to indicate (approximately) the case of CAL process applied without teacher's voice.

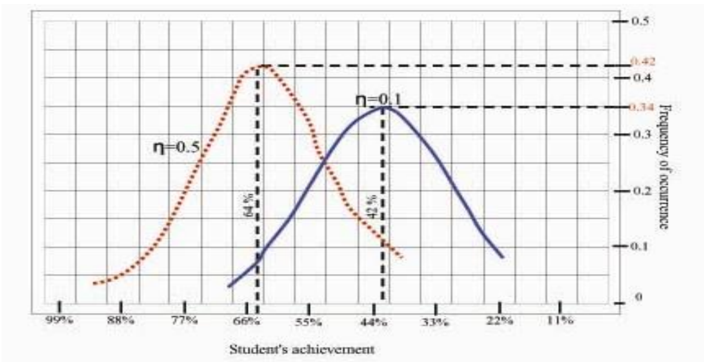

Figure 4. Simulation results presented by statistical distribution for children's (students) achievements versus the frequency of occurrence for various achievements values, at different learning rate values (η = 0.1& η = 0.5).

Simulation Results

The program list presented in Appendix II is designed for simulation of ANN supervised learning paradigm. It is written using MATLAB Version 6. This program corresponds specifically to dynamical changes of three weight vectors for supervised learning paradigm given by equation (6) (see. section III). Furthermore, the obtained results (after running the computer program) are depicted by considering some learning rate value (η = 0.4). A sample for two different learning rate values (η = 0.1 and η = 0.5) are presented graphically in Fig. 4. Additionally, other statistical parameters are given in Table II which includes the standard deviation ($\sqrt{\sigma}$) and coefficient of variation ($\rho = \sqrt{\sigma}$ / M).

TABLE III. SIMULATION RESULTS FOR DIFFERENT LEARNING RATE VALUES

Learning Rate value	Children's average Achievement score (M)	Variance σ	Standard deviation $\sqrt{\sigma}$	Coefficient of variation $\rho = \sqrt{\sigma}$ / M	Improvement of teaching Quality
η=0.1	42	428.5	20.7	0.61	-
η=0.5	64	918.1	30.3	0.47	66%

VI.CONCLUSIONS

This paper comes to two interesting conclusions:

- Evaluation of any CAL package quality is measured after statistical analysis of educational field results. So, the above suggested strategy provides specialists in educational field with fair unbiased judgment for any CAL package. That is by comparing statistical analysis of simulation results with natural analysis of individual differences obtained in by practice.
- After practical application of our suggested multimedia CAL package (case study), interesting results obtained considering diverse individual's learning styles. Obtained results are depending only upon two cognitive sensory systems (visual and/or audible) while performing learning process.
- Consequently, by the future application of virtual reality technique in learning process will add one more sensory system (tactile) contributing in learning process. So, adding of the third sensory (tactile system) means being more promising for giving more additive value for learning/teaching effectiveness. Finally, for future modification of suggested CAL package measurement of time learning parameters is promising for more elaborate measurement of learning performance in practical educational field (classroom) application. This parameter is recommended for educational field practice [42] as well as for recently suggested measuring of e-learning systems convergence time parameter [16].

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APPENDIX A

ASSOCIATED MEMORIZATION EQUATIONS

Consider $X_k^{'}$ and $X_k^{''}$ are the two vectors simulating heard and seen by input stimuli patterns respectively. Similarly $Y_k^{'}$ and $Y_k^{''}$ are the two vectors simulating pronouncing and visual recognizing output responses respectively. The two expected unconditioned responses are described in matrix form as follows:

$$Y_k^{'} = W(k) \cdot X_k^{'} , k = 1,2,3,...,q \qquad (1)$$

where W(k) is a weight matrix determined solely by the input-output pair $(X_k^{'}, Y_k^{'})$

$$y_{ki} = \sum_{j=1}^{r} w_{ij}(k) \cdot x_{kj} \ , i = 1,2,...,r \qquad (2)$$

where $w_{ij}(k),\ j=1,2,\ldots,r$ are the synaptic weights of neuron i corresponding to the k^{th} pair of associated patterns of input -output pair (X'_k, Y'_k). We may express y_{ki} in equivalent form.

$$y_{ki} = \left[w_{i1}(k), w_{i2}(k), \ldots, w_{ir}(k)\right]\begin{bmatrix} x_{k1} \\ x_{k2} \\ \ldots\ldots \\ x_{kr} \end{bmatrix} ;i=1,2,\ldots,s \qquad (3)$$

Similarly, for visual input stimulus X''_k and recognizing (of seen letter/ word) output response Y''_k

$$y_{ki} = \left[w_{ir+1}(k), w_{ir+2}(k), \ldots, w_{im-r}(k)\right]\begin{bmatrix} x_{kr+1} \\ x_{kr+2} \\ \ldots\ldots \\ x_{km-r} \end{bmatrix} \qquad (4)$$

$$i = s+1,2,3,\ldots,l$$

For conditioned response, the input hearing stimulus X'_k results in recognizing visual signal Y''_k. However, input seen letter/word stimulus X''_k results in pronouncing that letter/ word as conditioned response vector Y'_k which expresses the reading activity given by the equation

$$y'_{ki} = \left[w_{ir+1}(k), w_{ir+2}(k), \ldots, w_{im-r}(k)\right]\begin{bmatrix} x''_{kr+1} \\ x''_{kr+2} \\ \ldots\ldots \\ x''_{km-r} \end{bmatrix} \qquad (5)$$

$$i = 1,2,3,\ldots,s$$

In a similar manner, the other conditioned response for recognizing heard phoneme is described by the equation:

$$y''_{ki} = \left[w_1(k), w_2(k), \ldots, w_r(k)\right]\begin{bmatrix} x'_{kr+1} \\ x'_{kr+2} \\ \ldots\ldots \\ x'_{km-r} \end{bmatrix} ;i=1,2,\ldots,s \qquad (6)$$

As a result of the above equation, the memory matrix that represents all q- pairs of pattern associations is given by $m*l$ memory correlation matrix as follows:

$M = \sum_{k=1}^{q} W(k)$, where *W(k)* weight matrix is defined by

$$W(k) = \begin{bmatrix} w_{11}(k) & w_{12}(k) & \ldots & w_{1m}(k) \\ w_{21}(k) & w_{22}(k) & \ldots & w_{11}(k) \\ \ldots & \ldots & \ldots & \ldots \\ w_{l1}(k) & w_{l2}(k) & \ldots & w_{lm}(k) \end{bmatrix} \qquad (7)$$

This weight matrix relating input stimulus vector with m-dimensionality X_k connected by synaptic with output response vector Y_k with *l*-dimensionality. The complete relation for input/ output relation is given by the following equation.

$$\begin{bmatrix} y_{k1} \\ y_{k2} \\ \ldots. \\ y_{kl} \end{bmatrix} = \begin{bmatrix} w_{11}(k) & w_{12}(k) & \ldots & w_{1m}(k) \\ w_{21}(k) & w_{22}(k) & \ldots & w_{11}(k) \\ \ldots & \ldots & \ldots & \ldots \\ w_{l1}(k) & w_{l2}(k) & \ldots & w_{lm}(k) \end{bmatrix} \cdot \begin{bmatrix} x_{k1} \\ x_{k2} \\ \ldots. \\ x_{km} \end{bmatrix} \qquad (8)$$

It is worthy to note that the above equation represents memory correlation matrix after learning convergence. So, this matrix is given in other way as:

$$M = Y \cdot X^T \qquad (9)$$

The above equation illustrates that all the values of memory matrix M elements present synaptic weights relating key pattern X with memorized stored patterns Y. In other words, the relation between input patterns to the proposed model and that model's output patterns is tightly closed by the steady state values of the memory matrix M after reaching of learning convergence. Noting, that learning process well obeys the presented ANN model performance illustrated in Figure.2 (at the above manuscript).

APPENDIX B

Supervising Learning Algorithm for various Learning Rate η

```
w=rand(1000,1000);
x1=0.8; x2=0.7;x3=0.6; l=1; eta=0.4;
for g=1:100
nog(g)=0;
end
for i=1:1000
        w1=w(1,i); w2=w(2,i);w3=w(3,i);
        net=w1*x1+w2*x2;
         y=1/(1+exp(-l*net));
         e=0.9-y;
         no(i)=0;
   while e>0.05
         no(i)=no(i)+1;
          net=w1*x1+w2*x2+w3*x3;
          y=(1-exp(-l*net))/(1+exp(-l*net));
          e=0.9-y;
          w1=w1+eta*e*x1;
          w2=w2+eta*e*x2;
          w3=w3+eta*e*x3;
```

```
  end
end
for i=1:100
          nog(i)=0;
         for x=1:1000
         if no(x)==i
         nog(i)=nog(i)+1;
    end
  end
end
i=0:99;
plot((i+1),nog(i+1),'linewidth',1.0,'color','black')
xlabel('Itr. number'),  ylabel('No of occurrences for each cycle')
title('error correction algorithm')
grid on
hold on
```