

**CONNECTING THEORY AND PRACTICE:  
A CONNECTIONIST APPROACH TO SECOND  
LANGUAGE ACQUISITION**



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### Abstract

The purpose of this research is to identify the differences in the literature at describing connectionism as a model for Second Language Acquisition. Connectionism is a psychological, cognitive and computational theory that explains how second language learning is processed in the brain by means of computational simulation. The immediate outcome of understanding connectionism is to acknowledge its powerful implications for both teachers and learners of foreign languages. In this paper some of those presumptions will be illustrated in order to extract more and deeper links between theoretical brain research and its immediate applications in real contexts of foreign language acquisition.

### 0. Introduction

As theories and models for second language acquisition are still growing, the ongoing debate about how languages are acquired continues. However, there is a theory that is gaining ground in psycholinguistics, namely, connectionism. Such a theory may not be new for any scholar who studies psycholinguistics and language acquisition, mainly because it appears in many of the most well-known literature about psychological theories for language acquisition (Atkinson 2011; Cook 1993, 2008; Ellis 2003; Lightbown & Spada 2011; Mitchel & Myles 2006; Saville-Troike 2006). When reviewing this literature, we can easily reach two main conclusions. Firstly, some of those authors highlight how important connectionism might become in the following years; thus, they encourage us to keep connectionism always up-to-date. Thereby, a deeper literature review on connectionism is needed in order to acknowledge its applications and implications for SLA, since “many of the most important models in current psycholinguistics are types of connectionist models“ (Trevor, 2001, p. 457). Secondly, the labels employed by those authors differ when dealing with connectionism, mainly due to their scopes: some are more generic and others are more specialized. Thus, we should combine ideas found in the two types of sources so that we can better understand what connectionism is and what it might imply as a SLA theory. In this line, the main objective of this research is to set forth connectionism as a SLA theory, describing as well some possible applications in the process of foreign language learning. The subsidiary aims of this research are rather theoretical: to link connectionism to previous linguistic background, to account for the true role of

frequency for connectionist thinking, and to explain what the main model of connectionism is.

Connectionism, as any other model for second language acquisition, entails implications for the teaching methodology. As Li & Zhao pinpoint, it is only recently that scholars are exploring “the significance and implications of these models in language acquisition and bilingualism” (2013, p.178). However, as a model that is based on connections of neurons as processors of information inside the brain, the idea of applying such phenomenon to language teaching is not as new as Li & Zhao suggest. For instance, it was Trevor who laid the foundations for teaching implications when he explained how we process information both orally and written. He claims that any psycholinguist aims at explaining how the processing of language occurs and how learners acquire any language (2001, p.3). Besides, scholars such as Fred Genesee already hinted the importance of the implications of learning through connections (2000). Some of the most famous scholars working now in emergentism are also developing some ideas about how to apply connectionism. For instance, O’Grady describes the so-called usage based view (2007, p.11); Hulstijn suggests some different ideas about how good exercises on listening should be (2003, pp. 421-423); and Ellis and Savielle-Troike provide insight about the term U-shaped course of development (2003, p.23; 2006, p. 76), which implies a different view on the order of acquisition from the Chomskyan tradition.

Regarding structure, this essay will be divided into two main parts: a first part dealing with theoretical connectionism and a second one that tackles the applications and implications of connectionist thinking to SLA. In the theoretical part, there will be five sections. First of all, a general definition of connectionism will be provided. Secondly, connectionism will be presented as a psycholinguistic, cognitive and computational approach to SLA. Thirdly, an explanation will be provided of how a connectionist network works, namely, through the use of learning algorithms. Fourthly, the onset of connectionism will be described as well as the link of connectionism with other linguistic theories. Fifthly, conceptual orientations in connectionism will be analyzed. In the second section, there will be two parts. The first one will explain how connectionism was applied in the 1980s, chiefly to explain how language is processed in the brain. The second part will shed light on how connectionism can be linked to second language acquisition: connectionist models of bilingual learning and teaching and learning applications of connectionist thinking. Regarding these applications, three

issues will be dealt with, namely: feedback and writing, errors and order of acquisition, and language attrition. Through this research awareness will be raised of the fact that connectionism needs to be studied in a deeper sense to extract what its powerful implications and applications are in order to conceptualize foreign language learning.

## **1. Theoretical Connectionism**

### 1.1. Definition

Connectionism is a theory for learning in which knowledge is understood as an association between ideas; making connections of neurons in the brain. Then, learning is just the outcome of modifying the strength of those connections. They form complex networks processing information in parallel rather than serially; if two units are activated at the same time when a task is performed, then the strength of the connection increases (Williams, 2005, p. 2). As O'Grady points out, a network is a complex system of many dynamic and interconnected parts (Cambridge Encyclopedia, p. 1). According to the distinction made by Robert Cummins in 1983 (cited in Robinson, 2001, p.156), it can be seen as a transition theory rather than a property theory since it “explains how associative patterns emerge in learners” (Mitchel & Myles, 2006, p. 122) rather than a property theory which focuses more on the properties of the language system, its components, and its organization, i.e. Chomskyan tradition.

### 1.2. Connectionism as an approach to SLA

Connectionism is a cognitive, psychological, and computational-based model of language processing. It aims at setting forth how language is processed in the brain through the use of computational devices.

#### 1.2.1. The psycholinguistic approach

As a psycholinguistic approach, connectionism attempts to explain word recognition, reading, speech recognition, word meaning, speech production, language processing in dyslexic brains, and language acquisition. As it can be read in *Introducing Second Language Acquisition* (Saville-Troike, 2006, p. 27), connectionism is a psychological perspective in SLA that focuses on learning processes. Lightbown & Spada mention that this theory emphasizes the “frequency with which learners encounter specific features in the input and the frequency with which features occur together” (2011, p. 41). The model postulates that strong connections in our mind can

be correlated with very frequent structures found in the input; and weak connections with those that have very little frequency in the input.

### 1.2.2. The cognitive approach

As a cognitive approach to language, connectionism shares some common features with other cognitive theories (Cook, 1993, p. 267). First of all, it is based on the metaphor that the mind is a network in which everything is connected. Secondly, the learning process goes from being declarative, controlled, and demanding attention to gradually becoming a procedural, automatic, and a non-attended process. Finally, learning means to strengthen neurons through frequency of occurrence.

It is based on the interaction of different “cognitive phenomena: processing, working memory, pragmatic reasoning, perception, knowledge of lexical properties, and so on” (O’Grady, 2009, p. 122). As Richards & Schmidt define it, connectionism is “a theory in cognitive science that assumes that the individual components of human cognition are highly interactive” (Ghaemi & Faruji, 2011, 45). Two theories are ascribed to such description of language processing: nativist empiricism ideas and empiricist emergentism (Shakouri, 2012, p. 21). Both are emergentist theories, in the sense that language emerges from the interaction of the different phenomena already mentioned. However, the former is a type of connectionist theory based on the processor, and the latter a connectionist theory based on input. The processor as such does not exist; it stands for the innate ability to process. It is not “a concrete cognitive mechanism located at some particular point in the brain” (O’Grady, 2009, p. 123). The processor aims at reducing the burden of the working memory so that the brain, which makes less effort when the burden is reduced, pays more attention to processing information at higher levels like semantics (Hulstijn, 2003, p. 424).

### 1.2.3. The computational approach

As a computational approach, connectionism deals with concepts such as units, nodes, artificial neurons or neural connections. A computer processes these units serially; however, the brain is not as fast as a computer and needs to process them in parallel. These “connections can have different levels of strength” (Li & Zhao, 2013, p. 179). In other words, their activation varies according to the strength they have acquired through the use of learning algorithms by the brain. This activation is due to the weight it has in the network; which can thus be defined as a “unique combination of weight and

activation pattern of nodes; representing different input patterns from the learning environment” (Li & Zhao, 2013, p. 179). If a linguistic element is found on the input many times, then it will be easier to process it. This would be the explanation of why people use pro-words like “*thing*”. It is easier to recall such pro-word than spending cognitive effort attempting to employ the specific noun that should be applied in such context (“Give me that thing” instead of “Give me that X”; X standing for any noun), Thing is a word that can be found in the input in a greater extent; this word carries a huge activation in the brain because it can be linked to any other word. Therefore, there is more chance for connections to be made, leading to an increase of the weight and activation value of such linguistic element; the weight and the activation pattern are continuously adapted during the process of learning.

### 1.3. Learning algorithms

The brain carries out several algorithms when processing language; these learning algorithms adjust the weight of a network. These learning algorithms can be classified into two main categories: supervised and unsupervised<sup>1</sup>.

#### 1.3.1. Supervised learning algorithms

A supervised learning algorithm consists of 3 layers: the input layer, which receives the information; the output layer, which produces the outcome of the working of the network; and the hidden units, where the network is created. The most famous supervised algorithm is the so-called backpropagation developed by Rumelhart et al in 1986. Its formulation is as follows:

$$\Delta w = \eta * \zeta$$

In this formula,  $\Delta w$  stands for the change of weight;  $\eta$  for the rate of learning and  $\zeta$  for an error –which is the discrepancy between the actual output and the desired output (Li & Zhao, 2013, p. 180). This means that the brain carries out the delta rule whenever the actual output does not match the desired output. For instance, when a person says the utterance “\**He like chocolate*”, then the neural system subconsciously

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<sup>1</sup> The main learning algorithm used in connectionist language processing is the supervised algorithm. In this section, this is the type that will be explained. In order to know about the unsupervised learning algorithm please see appendix 1.

realizes that it has not used the morpheme “-s” for the verb; the brain carries out a backpropagation algorithm, minimizing the strength of the connection “\**He like*” so that the system attempts to avoid committing this error the next time since its weight has been decreased. In this sense, we are dealing with statistics and mathematical phenomena rather than with following abstract linguistic rules. Nevertheless, it is very likely that the same person commits the same error repeatedly until the brain totally destroys the ill connection. The person already knows the rule; however, when these two separate units (3<sup>rd</sup> person singular + verb “to like” in present simple) are processed automatically, the actual output might not match the desired output because such ill connection still exists in the brain.

An important connectionist model for language based on supervised learning is the Simple Recurrent Network (Li & Zhao, 2013, p. 180) developed by Elman in 1990. The aim of such model is to predict words in a sequence by modifying its weight thanks to a backpropagation algorithm and a recurrent layer of context units; which keep a copy of the representations of the hidden units to apply them to new input.

#### 1.4. Connectionism: history and link with other linguistic theories

Connectionism can be linked to previous linguistic theories and philosophical paradigms. The following table shows visually the connections that will be tackled in the theoretical part of the body of this research.

LINGUISTIC THEORY	YEAR	REPRESENTATIVE
<b>1-Behaviorism</b>	-1904 -1940s-1950s	-Edward L. Thorndike (Connectionism) -B. F. Skinner (Operant Conditioning)
<b>2-Artificial Intelligence</b>	1950s, 1980s	David E. Rumelhart
<b>3-Nativism</b>	1960s-1970s	Noam Chomsky
<b>4-Adaptative Control of Thought*</b>	1983	John Robert Anderson
<b>5-Competition Model</b>	1981, 1987, 2005	B. MacWhinney
	2012	B. MacWhinney (Unified Competition Model)
<b>6-Optimality Theory</b>	1993	A. Prince & P. Smolesnky

Table 1. A visual representation of the history of connectionism and its link with other linguistic theories.

### 1.4.1. Behaviorism

Connectionism is a theory that can be traced back to the onset of the 20<sup>th</sup> century, thanks to Thorndike and his connectionist ideas. He anticipated Skinner's operant conditioning and behaviorist ideas based on the reward<sup>2</sup>. Thorndike postulated the Law of Effect in 1905 whereby learning was explained in terms of strengthening or weakening of connections between stimuli and response (Leahey, 2005, p. 405). Thorndike believed that the weight of the connections is the outcome of the satisfaction obtained from the response. In other words, like Skinner in his operant conditioning, a child would learn a language structure because the father or mother would reward such structure. For instance, the weight of the connection of a word like "Daddy" would increase because the father would smile at the child. In this sense, both theories claim the importance of environment; the need to look for information in the background to build a good stimulus.

One of the main tenets of behaviorism, based on its positivist origin, is the fact that all behavior must be observable in order to be studied. This is the main difference between behaviorism and connectionism; connectionism has developed a theory of the brain, which behaviorist could not observe, and its layers. Connectionism is based on how this brain processes language internally; it is the explanation of the connection of both internal and external phenomena: from the input that the brain receives from the environment, going through the mental representations created by learning algorithms in the hidden units, to the final outcome that the output layer produces. The connectionist idea of the processor-based emergentism opposes behaviorism because it deals with the internal representations and how the brain processes them. However, input-based emergentism is more similar to behaviorism in the sense it deals with environment; the weight of connections has much to do with the frequency of the input as stimulus. Nevertheless, it is important to bear in mind that this frequency relates to the establishment of connections between form and function in the internal representation of the hidden units. For a linguistic element to be learnt and its weight to be increased, there must be a mapping of the form and function in the brain, based on frequency of occurrence and strengthened by the satisfactory outcome of the output. If a person continually finds that the first word employed when people encounter is *hello*, he will interpret that such word stands for a salutation. When the learner creates the mapping

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<sup>2</sup> Thorndike's Law of Effect postulated that those behaviors producing a reward would be learned and stamped in the brain in order to be reproduced again.

“hello-greeting”; he will employ it when willing to greet. If he receives the same salutation (the satisfactory outcome), the word will be reinforced in the mapping. Behaviorism and connectionism differ in the sense that the latter deals with massive connections in parallel rather than simple associations of stimulus and response.

#### 1.4.2. Artificial Intelligence

However, the new connectionism that is dealt in this paper has its origins in its golden age in the 1980s with the work of a research group led by David E. Rumelhart – a former leader in the field of Artificial Intelligence (AI) (Leahey, 2005, p. 405). Their work *Parallel Distributed Processing: Explorations in the Microstructure of Cognition* set the bases of all posterior research in connectionism: the mechanism of parallel distributed processing (PDP), a machine preprogramed to imitate the processing of any brain. This complex task was finally possible because of the great breakthrough in computer science and psychology. This new connectionism was appealing for researches for two main reasons: first, that AI was not able to build a machine that reproduced the behavior of a human without thinking –like recognizing patterns; and secondly, that AI’s idea of sequential processing did not resemble the brain’s working (Leahey, 2005, p. 407). The brain has many interconnected neurons; connectionist models could emulate the brain in the sense they had an input layer activated by the weight of the connections producing an output according to such weight (Leahey, 2005, p. 407). After becoming independent from AI, Connectionism defied the paradigm of symbolism; which explained intelligence in terms of employing symbols following formal rules. Connectionism highlights that obeying rules is just applied in the conscious level; the intuitive processing is parallel and non-symbolic alike the neural processing in the brain (Leahey, 2005, p. 410).

#### 1.4.3. Nativism

In current cognitive neuroscience, connectionist tenets are to be taken into account when considering neural working and learning since the most automatic and unconscious processes are of connectionist nature (Leahey, 2005, p. 411). However, these ideas are not taken for granted by all scholars. There is still an ongoing debate between the dichotomy rule-obeying and not-rule-obeying behavior mostly incarnated by nativists and connectionist scholars. Nativists contend that language processing is determined by obeying innate language abstract rules. For connectionist theories,

language processing is based on networks mapped in the brain that reproduce linguistic behaviors following probabilistic and statistical phenomena. The process of acquisition should be explained in terms of activation of networks whose weight increases or decreases to match linguistic behavior found in the environment. Besides, connectionism can also be compared to Chomskyan ideas when dealing with the processor-based emergentism. According to the emergentist O'Grady, what is really innate in language is the ability to learn it (what he named the processor) rather than innate language properties found in our brain. In this sense, Chomsky's Language Acquisition Device is not the same as O'Grady's processor because the former stands for an innate mechanism and the latter stands for the process itself. This relates to the distinction of the scope of both theories: Universal Grammar is a property theory and connectionism is a transition theory.

According to Chomsky, the brain is multimodular, language having a specific innate module in the brain. Connectionism, and cognitive theories in general, opposes this idea; the brain is also a complex system but it is unimodular<sup>3</sup>. The main and direct implication of this fact is that learning a language is like learning any other cognitive skill. The brain carries out the same process when learning a language than when learning how to drive a car, for example.

#### 1.4.4. Adaptative Control of Thought\*<sup>4</sup>

Connectionism can also be associated with another cognitive theory, namely, Anderson's Adaptative Control of Thought\* (1983). This model postulates three forms of memory: working memory, which is used for the actual production; declarative memory, used for storing actual information in the form of cognitive units such as proposition or images; and procedural memory, which can be defined as the pragmatic one, knowing how to carry out an activity. It claims that learning consists of three stages: the declarative stage, which is learning rules; the associative stage, which has to do with applying the rules; and the autonomous stage, which encompasses the task of generalizing productions to other conditions (Cook, 1993, p. 249). ACT\* model and connectionism are similar in the sense that both emphasize the role of activation: when

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<sup>3</sup> According to connectionist thinking, the brain is unimodular, which refers to the fact that language does not have a specific and separate module in the complex neural system. The main implication of this neural organization is that the process of learning a language in the brain is exactly the same than any other type of learning.

<sup>4</sup> The asterisk stands for the ultimate version of the model in 1983 (Cook 1993, p. 246)

we compare two structures matched to a single pattern, the ACT\* will prefer the more active one. Both ACT\* and connectionism define the mind as a network that builds up strength through practice. However, two important differences between the models have to be mentioned: firstly, connectionism denies the need for a separate declarative and procedural memory system –a distinction essential in Anderson’s model; and secondly, connectionism defines learning as the strengthening of connections rather than the point where the nodes meet as in Anderson’s model (Cook, 1993, p. 265).

#### 1.4.5. Competition Model

MacWhinney’s Competition Model (1981, 1987, 2005) is a theory rooted in connectionism and complementary to Anderson’s ACT\* model. It is a functional approach to language, as connectionism is, since all linguistic performance involves mapping between external form and internal function. SLA involves adjusting that mapping, the internal representations formed in the hidden units of connectionism. This task is accomplished by detecting cues (word order, agreement, case, and animacy) are in language input, which are associated to a particular function, and by recognizing their weight or cue strength.

These cues are presented and processed simultaneously, competing among them (Saville-Troike, 2006, pp. 80-81). For example, this unconscious process occurs when analyzing texts (both orally and written). In the utterances “George has come with his baby dogs at home”; these cues compete in order to provide the sentences with an appropriate meaning. In the first sentence it is acknowledged that the subject is George because of animacy (*George* is a human being), agreement with the verb (*George-has*), word order (first subject position), and case (the pronoun *his* refers to the possession of the subject). All of these cues signalize the subject, however, the main reason we automatically know that George is the subject has to do with the fact that he is a human or that it is the first constituent of the sentence rather than the use of the pronoun. Another example can be found in the use of long-distance questions: “What did Peter tell Helen that we should buy?” In this sentence, it can be perceived the strong animacy cue due to the fact that there are three human entities. However, it is word order the cue that points out the subject.

In this sense, Competition Model is a probabilistic-bounded theory, since the processing outcome is determined by statistical characteristics of the input and the learning characteristics of language. A more recent version of Competition Model, the

so-called Unified Competition Model, 2012, postulates, “those who can maximize the benefits of the protective factors (immersion, active thinking in L2, and the internalization of L2 speech) will end up with better learning outcomes in the second language” (Li & Zhao, 2013, p. 184).

#### 1.4.6. Optimality Theory

Another interactive theory for SLA is Optimality Theory, developed by Prince & Smolensky in 1993. It highlights that there is set of constraints shared by language users, and these constraints can be ranked with regard to the hierarchy or level of importance values for processing or learning each language... The observed forms of language are the optimal outputs with the maximum harmony from the interaction of these conflicting constraints based on their importance levels. This model “resembles the search for minimum error in connectionist models” (Li & Zhao, 2013, p. 183).

#### 1.5. “Recent”<sup>5</sup> conceptual orientations in connectionism

Atkinson highlights the importance that connectionism has gained nowadays when he claims that “the static, experience-distant nature of internalist cognitive models has spurred the growth of a powerful alternative: connectionism” (2011, p. 162). However, Atkinson rejects connectionism as a plausible model to explain SLA because it comes from statistical phenomena and physics rather than biology. Thereby, connectionism is not described in Atkinson’s book of theories for SLA but it is merely negatively commented in some of the articles compiling the book. However, this section will deal with connectionism as a model for SLA; coping with specific information and updated ideas on connectionism found in the literature review that originated the rationale for this research on connectionism.

Scholars such as Cook (1993, 2008), Ellis (2003), Larsen-Freeman (2011), Lightbown & Spada (2011), Li & Zhao (2013), Mitchel & Myles (2006), O’Grady (2009), Saville-Troike (2006), and Shakouri (2012) describe connectionism as a theory for SLA, but it is only in Saville-Troike’s *Introducing Second Language Acquisition* where a taxonomy of language acquisition theories and the place connectionism occupies in such historical background can be found (2006, p. 24). Connectionism is classified as a psychological model of SLA of the 1980s whose main aim is studying

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<sup>5</sup> The conceptual orientations of connectionism mentioned in this section are described as recent, bearing in mind that most of them belong to articles and books published in the 21<sup>st</sup> century.

learning processes (2006, p. 28). Saville-Troike's explanation of connectionism might be considered interesting for two main reasons: the importance of frequency in a connectionist network and the relationship between connectionism and Bates-MacWhinney's Competition Model. Regarding the first issue, Saville-Troike's interpretation of the model leads the reader to think that the bases of connectionism are based on frequency of the input when it is actually frequency of associations in the brain (Cook 2008, p. 221). Secondly, Bates-MacWhinney's Competition Model is set apart as a theory different from connectionism; when Competition Model is actually a theory deriving from connectionist thinking (2013, p. 183). However, what can be read in Cook is that connectionism and Competition Model are linked (1993, p. 257). Connectionism encompasses Competition Model in the sense that the latter is based on the idea of processing information in parallel, task frequency and associative learning, which are the basic tenets of connectionism.

Lightbown & Spada also agree on linking connectionism and Competition Model in the sense both theories deny an innate module for language (2011, p. 42). This tenet is also highlighted in Ellis; although connectionism as such is not mentioned but rather parallel distributed processing or PDP (2003, p. 62). PDP does not only reject the Chomskyan innate module for language but also the existence of language rules. In Cook it can be read that the main model of connectionism is Information Processing, McLaughlin et al., 1983 (2008, p. 221); when Saville-Troike clearly distinguishes Information Processing and connectionism (2006, pp. 80-81). For example, based on connectionist thinking, knowledge is not stored in memory or retrieved patterns, as in Information Processing, but as connection strengths.

Emergentism is an essential concept to fully acknowledge what connectionism is. This term encompasses cognitive theories like connectionism (Mitchel & Myles 2006, pp. 98-99), which denies the innate language acquisition device. As can be read in Shakouri 2012, connectionism is part of Nick Ellis' empiricist emergentism, which explains language learning in terms of neural networks due to the frequency of the input. This is opposed in nature to O'Grady's nativist empiricism, which explains language learning due to the action of a processor that stands for the innate ability to learn (2012, pp. 20-21). However, O'Grady himself explains his emergentism as a model deriving from connectionism that only differs in the symbolic approach to grammatical principles that are not well accepted by connectionist scholars (O'Grady, Emergentism, p.2). Larsen-Freeman also believes that connectionism is subscribed to emergentism

since connectionism cannot explain linguistic creativity; people do not merely reproduce what they hear from others (2011, p. 56). Thus, connectionism, being subscribed to emergentism, can explain that novel forms “arise through overgeneralization and social interaction in contexts of natural language acquisition” (Larsen-Freeman, 2011, p. 69).

What can be concluded after reviewing recent trends in connectionism is the need to keep this theory up-to-date since connectionist principles pervade current psycholinguistic models. Thus, a deeper understanding of the theoretical principles of connectionism might help students interested in language processing to infer their importance into those psycholinguistic models. For example, one connectionist tenet that has been described in this paper is the role of frequency. Its importance is outstanding for neural networks, but it refers to the frequency of association of nodes in the brain rather than the mere encounter of linguistic items in the input. Furthermore, it has been clarified which place connectionism occupies as a theory of learning.

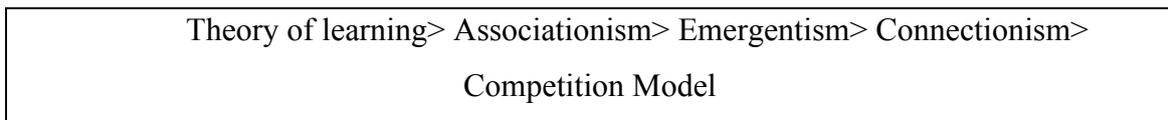


Figure 1. The place of connectionism as a theory of learning.

## 2. Applied Connectionism: Applications and Implications

As it can be concluded from the first part of this paper, connectionism is quite a theoretical field of knowledge. Most of the information that has been provided tackles with abstract tenets about language processing; however, its applications can be also difficult to discuss. In this second part, applications of connectionism will be dealt with.

### 2.1. Connectionism applied in the 1980s

The golden decade of connectionism was the 1980s. Thus, many connectionist models were put into practice through the use of computational devices in order to explain language processing. Models of word recognition, reading, and spoken word recognition should be highlighted: IAC, PMSP, and TRACE.

#### 2.1.1. Interactive Activation and Competition (IAC)

IAC stands for Interactive Activation and Competition. It is a connectionist model of visual word recognition developed by Rumelhart and McClelland in 1982. As

Trevor mentions, its main purpose was to “account for word context effects of all connectionist models” (Trevor, 2001, p. 178). As it is based on supervised learning algorithms, the model consists of three layers: the input layer made of visual traits; the hidden units, where those traits are associated to individual letters; and the output layers, where each unit is linked to a word. Those connections can be excitatory or inhibitory; for example, the letter “t” would excite words beginning with that letter such as “take” and inhibit the rest, for instance “cake”. When “t” is perceived, its activation spread throughout the networks in parallel; all words starting by “t” are activated a little. As soon as more letters are perceived, fewer words are activated but with a greater strength; they compete until one reaches the output level.

#### 2.1.2. PMSP (Plaut, McClelland, Seidenberg, and Patterson)

PMSP is a revised connectionist model of an older version developed by Seidenberg and McClelland. It is based on the IAC model, thereby, it deals with interactive and competitive connections that excite and inhibit other connections by means of propagated activation. The network learns to associate phonological production with orthographical input; regularities found on the input are mapped into the network in a statistical manner. Semantics can be accessed directly through orthography or indirectly, from orthography through phonology until reaching semantics. This process is influenced by “frequency of exposure to the pattern” (Trevor, 2001, p. 216).

#### 2.1.3. TRACE

TRACE is a connectionist model of spoken word recognition developed by McClelland & Elman in 1986 (it is a model quite influenced by the interactive nature of McClelland and Rumelhart’s PDP). It is a top-down processing in which context plays a major role. TRACE is based on supervised learning algorithm, that is, networks are composed of three parts: the input layer, the hidden units and the output layer. “The level of input units represents phonological features; these are connected to phoneme units which in turn are connected to the output units that represent words” (Trevor, 2001, p. 250). As a dynamic system, the level of activation that the input receives is spread throughout the network until it reaches the output layer, where only one output remains. Word recognition works in this manner; the word that is recognized is the winner of

such process. It is an inhibitory process in the sense the winner inhibits its competitors. As Trevor points out, the context and position of letters have an inhibitory effect.

## 2.2. Connectionism applied to foreign language acquisition

### 2.2.1. Connectionist models of bilingual learning and language attrition

Although connectionism has been applied to explain a wide variety of language behavior, there are just a few connectionist models dealing with processing of multiple languages. For this reason we shall just comment on connectionist models of bilingual learning. Based on their emergentist nature, “Thomas (1997) used a Bilingual Single Network (BSN) model to learn the orthography to semantics mapping in word recognition” (Li & Zhao, 2013, p. 184). This model consists of a supervised learning algorithm that uses the backpropagation algorithm: turning word’s form into its meaning. The model is exposed to words in L1 and L2, developing words in both although the L1 receives more input.

This model expects to set forth language independence and language interaction within a single network. When the same task is carried out at the sentence level, with more chances to intermix words from one language to the other, the hidden units carry out representations of words correctly categorized by languages without intermixing. Thus, it aims at proving that “invoking separate processing or storage mechanisms for the different languages” is not necessary for “the development of distinct mental representation of each language” (Li & Zhao, 2013, p. 185). In this line, Li and Farkas (2002) have developed a Self-Organizing Map for Bilingual Learning (SOMBIP) in which the input from which the models extract information comes from corpora; obtaining the same results than the BSN and the BSRN. The outcome of connecting a map trained on phonological representations to a map trained on semantic representations in two languages “suggests that natural bilingual input contains necessary and sufficient information for the learner to differentiate the two languages” (Li & Zhao, 2013, p. 186).

All these connectionist models account for language processing in the context of foreign language; studying English as a foreign language implies continually listening to words in both English and L1. Bilingual learning explained in connectionist terms addresses one of the main concerns parents whose children study in a CLIL context have, namely, if children are taught in English they will lack vocabulary in Spanish.

Based on connectionist evidence, children (and also adults) are able to process words in both languages differentiating them without explicit explanations.

## 2.2.2. Teaching and learning applications in SLA

### 2.2.2.1. Feedback and writing

As it was mentioned before, connectionism is a model based on statistical phenomena rather than language rules; the output layer produces outcomes learnt from the input received. Magliano & Graesser comment on the success of “statistical representations of world knowledge. [...] The statistical, corpus-based representations of meaning are somewhat simple but, nevertheless, powerful estimates of the extent to which student responses reflect key constructs and expectations” (2012, p. 614).

Magliano & Graesser contend that computers can aid educators when evaluating student-constructed responses (2012, p. 609). These types of responses are not normally required to students because some teachers “do not have the time or, perhaps, expertise to evaluate them and provide critical feedback” (2012, p. 608). This is the reason why teachers could incorporate these automated systems that, based on algorithms, “assess the responses, make inferences about student learning, and make decisions to provide appropriate feedback” (2012, p. 609). They “compare the students’ verbal responses with expected [such as words, scripts, sets of essays grades in the past, and criterial dimensions] responses that are specified by some rubric, or what we call expectations” (2012, p. 609).

Magliano & Graesser argue that, although these systems have certain limitations when providing feedback, since it is not as accurate as the one provided by the teacher, they can improve students’ writing skills over weeks (2012, p.609). It is important to mention that not all essays are of a short extension, which in natural language processing simply requires “word- and pattern-matching algorithms”, and then “it is advisable to utilize high-dimensional semantic spaces for longer responses” (Magliano & Graesser, 2012, p. 618).

A connectionist high-dimensional space would be Latent Semantic Analysis (LSA). It is “a mathematical, statistical, technique for representing knowledge about words and the world on the basis of a large corpus of texts that attempts to capture the knowledge of a typical test taker” (Magliano & Graesser, 2012, p. 615). The system intuitively similar words, understanding similarity as co-occurrence: “two words are similar in meaning to the extent that they share similar surrounding words” (Magliano &

Graesser, 2012, p. 615). Based on singular value decomposition of large corpus, the system provides items with values ranging from 0 to 1, as in a backpropagation algorithm, establishing cosines of words. “For example, the word *car* is highly associated with words of the same functional context, such as *engine*, *race wheels*, *parking*, and *transportation*. [...] LSA is useful in the analysis of student-constructed responses because it is sensitive to inferences and to both proximal and distal semantic relationships” (Magliano & Graesser, 2012, p. 615).

Applying this connectionist model to provide immediate feedback to students writing long essays can be quite interesting; there is now research being carried out to attempt to make it “more accessible to practitioners and teachers” (Magliano & Graesser, 2012, p. 618). For example, the software Gallito 2.0 is the outcome of such an attempt; this program can “quantify the semantic relationships between texts, measure the cohesiveness between paragraphs in a text, extract the key words that summarize a document, [...] serve to assess text quality, and change the basis to obtain a new semantic representation of language” (“Basics of Gallito”)<sup>6</sup>. Once more research is conducted on this issue, teachers will be able to implement this type of connectionist software programs in order to help both students and teachers improve student responses. The use of a program such as Gallito 2.0 entails for the student more motivation, because it involves working with a computer, and concurrently a better performance, since the student will be encouraged not to copy from the sources when writing and rather paraphrasing or creating his/her own ideas. When a student is asked to carry out a summary of a text, this program prevents him from plagiarizing from the original source since it has an algorithm that takes into account words, symbolic expressions, sentences, paragraphs, scripts, sets of essays graded in the past, (and) criterial dimensions” (Magliano & Graesser, 2012, p. 609). In other words, there is a semantic analysis of the matches between the student’s performance (output) and the expectations (the original text, the input). Regarding teachers, it cannot be argued that these automated programs can substitute their labor, but it can assist them in correcting tasks.

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<sup>6</sup> UNED has carried out some research on this software; for instance, the Department of Evolutive Psychology and Education employs Gallito 2.0 in order to provide students with immediate assessment in their responses. For a visual representation please see appendix 2.

### 2.2.2.2 Errors and order of acquisition

Following a Piagetian tradition, the concept of U-shaped course of development<sup>7</sup> is also quite interesting for connectionist scholars. It refers to the fact that “initially learners may display a high level of accuracy only to apparently regress later before finally once again performing in accordance with target-language norms” (Ellis, 2003, p. 23).

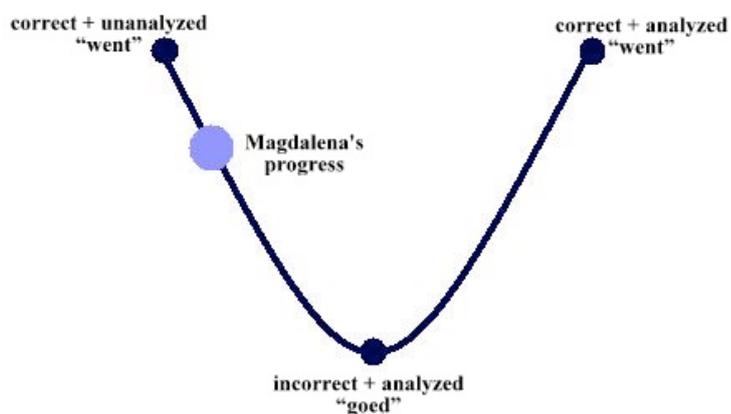


Figure 2. An example of a case of U-shaped course of development in learning the past simple of the verb “go”.

This phenomenon has to do with the concept of accommodation, the brain restructures itself before acquiring; students may commit mistakes of overgeneralization, for instance, applying regular forms of the past participle to irregular forms like in “ate” after a period of good performance. However, although it is an error, a discrepancy between the actual output and the expected output, is actually a good sign because the brain is restructuring itself by means of backpropagation algorithms. All these errors are being processed in the hidden units for some time after finally matching the desired output. The error happens because of the frequency of the input and frequency of the neural connections; for instance, “feet” is firstly learned as item in the network. However, the strengthened network in this case is employing the morpheme “-s” to refer to more than one item of a kind. Thus, the learners starts using the word “foots”;

<sup>7</sup> It is called U-shaped because the development follows a U curve: firstly, high level of accuracy, then a lower one, and then it recover the high level. Figure 2 shows a case of the verb go (taken from <http://myadventuresintucson.blogspot.com.es/2012/03/u-shaped-curve-of-development.html>).

this occurrence is not found in the input, thus the node is broken after a certain time because it competes with “feet” that is more common in the input: “feet” is strengthened and “foot” is weakened. This is a different manner of explaining grammatical exceptions from the traditional Chomskyan view.

To acknowledge this fact implies two main issues for language learning and teaching. Firstly, that when assessing and grading our students’ performances, some errors need not to be directly corrected or addressed because they have to do with this subconscious process that just need time to be correctly developed –as the evidence shown in the literature about correcting directly mistakes to children does not help them to improve their performance. In this line, this might have implications for assessment in primary and secondary schools where second languages are courses as any other type of subject. Teachers must be aware of the U-shaped course of development, because it hints the need to have a continuous assessment in any language course. A student can pass the first term because he is able to perform well when dealing with a certain linguistic item, but failing the second one because of this restructuring event. When the teacher finally grades the student at the end of the course, this teacher must take into account whether an accommodation process took place or not. Secondly, as learning is a matter of time, explaining this fact to students who are not confident might help them not to feel frustrated when learning a second language. They may be willing to avoid practice the language because they feel they are not good at it; however, this is contraproductive because what they really need is to practice the language so that the system can restructure itself and not fossilize.

### 2.2.2.3. Connectionism and language attrition

Connectionism implies for language acquisition studies a deeper study not only in language acquisition but also in language attrition. Connectionism has studied language loss in relation with semantic knowledge. “Connectionist models suppose that human semantic memory is based on microfeatures [...] which mediate between perception, action, and language, and do not necessarily have any straightforward linguistic counterparts” (Trevor, 2001, p.327). Meanings thus are simple patterns of activations spread in a complex system of microfeatures<sup>8</sup>. Language attrition accounts for the loss of those microfeatures, which leads to a decline in performance.

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<sup>8</sup> These microfeatures can be intercorrelated or distinguishing features. The former refers to features that occur together, representing units (hyponymy or meronymy would be explained in this sense). The latter

Regarding second language acquisition, connectionist models are useful to explain language attrition in that it “refers to the situation that bilinguals lose the skills of one language due to the dominant usage of another one” (Li & Zhao, 2013, p. 186). Connectionist models can turn this fact into an experimental science thanks to the use of computers. For example, scholars like Zinszer and Li (2010) have developed a connectionist model whose input comes from real corpora: production accounted for semantic representations connected to phonological information; and comprehension was represented by a link starting in phonological information connected to semantic representations. These two types of information were found in both Chinese and English; two self-organizing maps connected by Hebbian learning<sup>9</sup> (Li & Zhao, 2013, pp.186-7). They first trained the software in Chinese and afterwards in English. They obtained several outcomes: L1 gradually decays after training L2; a more sudden attrition in production than in comprehension occurs; and a late beginning of learning a language will provoke a quicker attrition.

### 3. Concluding remarks

Genesee, a cognitive psychologist in the bilingual setting of Canada, already hinted some years ago that “by understanding how the brain learns naturally, language teachers may be better able to enhance their effectiveness in the classroom [...] Learning by the brain is about making connections within the brain and between the brain and the outside world” (2000, p. 2). He also dealt with learning as simultaneous activations in parallel; “as exposure is repeated, less input is needed to activate the entire network” (2000, p.3). The implications he highlights for teaching are that teachers should teach in parallel: for instance, combining phonetics with semantics. Skills must not be taught in isolation; and they must be taught continually because it is only through experience and practice that students consolidate new skills and knowledge.

Genesee was making a call for teachers of a second language to take brain research into account. This research has been made chiefly in the fields of neurolinguistics and psycholinguistics. Connectionism is now the outcome of both fields when dealing with learning theories. One of the main aims of any psycholinguist is to attempt to set forth how language is processed in the brain and how it is acquired.

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refers to features that enable distinguishing categories (for example, hair makes distinction between mammals and other kinds of animals).

<sup>9</sup> The concept of self-organizing map is described in appendix 1. Hebbian learning means that the two maps are connected by co-occurrence and neighborhood in the neural network of the words employed.

The new connectionism was born in the 1980s, developed by Rumelhart et al. as a reaction to the Chomskyan paradigm and the nativist and symbolist theories. The only nativist idea that can be found in current connectionism is the processor, the fact that all humans share an innate ability to learn. Connectionism is closer to behaviorism than nativism in the sense that the environment is a key factor for learning. However, unlike traditional behaviorism, new connectionism focuses on internal mental processes; and the real frequency that matters is the one of networks.

The main problem with connectionism as a SLA theory, as this paper has reflected, can be defined as follows: “connectionist research is resolutely theoretical with very little effort expanded on solving educational problems” (Shultz, 2007, p. 1497). The subsidiary aims of this research go in this theoretical line: connectionism has been linked to other linguistic theories, the role of frequency for connectionist thinking has been explained, and connectionist models have been dealt with. However, The main objective of this research was to raise awareness of the fact that connectionism is not only an abstract field of knowledge but also a source for powerful applications in the process of foreign language learning. Connectionism was already applied in the 1980s in order to explain how language was processed in the brain by means of computational devices simulating this event. However, there is research being done nowadays to explain bilingual learning, to confirm hypotheses that link age of onset and learning, and to describe language attrition.

To conclude, connectionism, as a model based on statistical phenomena, implies a different view on traditional and taken-for-granted ideas such as errors, fossilization and language attrition, or order of acquisition. Additionally, connectionism also implies new research in the field of natural language processing and its role in foreign language acquisition. Personally, I think it is a matter of time that connectionism becomes more and more familiar, both in theory and practice, to foreign language teachers. As research continues studying the brain and its link to computer science, the applicability of connectionism will be more evident; merging once again computer scientists and linguists into the field of foreign language acquisition.

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## 5. Appendix

### APPENDIX 1: Unsupervised learning algorithm

Unlike supervised learning models, unsupervised do not use “explicit error signal at the output level to adjust the weights” (Li & Zhao, 2013, p. 181). The most well-known unsupervised model is the self-organizing map -SOM; Kohonen 2001-, which organizes input into two-dimensional topographical maps. Nodes in the networks pick up input patterns randomly and they are presented to the network also randomly. The weights and values of the patterns are compared and if they are similar the activation will be higher; thus, all input patterns are associated to a response in the map. Representations obtained from those learning models may derive from real corpora through the use of statistics based on frequency or from less natural input, namely, empirical data aimed at “generating the features describing the meaning of words” (Li & Zhao, 2013, p. 183).

### APPENDIX 2: A Visual representation of Gallito 2.0

This graphic has been taken from the course *Psychology of Education* at UNED. Students were asked to carry out a summary on “Expertise in problem solving”. This summary should contain information on expert knowledge, metacognitive strategies, innate ability, the role of practice, and a theoretical context. This feedback shows that the person has written a good summary because the middle line is between the peripheral axes in all the topics. This feedback was provided to the student immediately after he had finished it; thus, the student receives confirmation that the text can be sent to the teacher.

