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# Content-Based Instruction Understood in Terms of Connectionism and Constructivism

STEPHANIE LAIN

*University of California, Santa Cruz*
***E-mail:*** *lain.steph@ucsc.edu*

Despite the number of articles devoted to the topic of content-based instruction (CBI), little attempt has been made to link the arguments for CBI to research in cognitive science. In this article, I review the close alignment of the CBI model of foreign language (FL) with two emergent frameworks in cognitive science: connectionism and constructivism. I show that these frameworks offer powerful support for the features of CBI that make it an attractive alternative to textbook-based learning. In addition, I argue that the general principles associated with connectionism and constructivism suggest further avenues for development within CBI, especially in the areas of pattern recognition and speech processing.

To describe connectionism and constructivism as emergent frameworks in cognitive science is perhaps misleading. They would be better described as landmark theories that have in recent years experienced a revival, in large part due to the influence of research associated with increased brain imaging capabilities and large-scale computational modeling. Connectionism and constructivism originally stem from separate disciplines (mathematics and psychology, respectively). Conceptually, however, they are sufficiently broad as to have implications for many different fields. Taken separately or together, connectionism and constructivism have been especially influential in fields that deal with behavioral phenomena. Where there is an intersection between biology and culture, connectionism and constructivism provide the kinds of insights into learning that are otherwise difficult to untangle from a purely nature or purely nurture perspective.

## INTRODUCTION

Despite the number of articles devoted to the topic of content-based instruction (CBI), little attempt has been made to link the arguments for CBI to research in cognitive science. In this article, I review the close alignment of the CBI model of foreign language (FL) with two emergent frameworks in cognitive science: connectionism and constructivism. I show that these frameworks offer powerful support for the features of CBI that make it an attractive alternative to textbook-based learning. In addition, I argue that the general principles associated with connectionism and constructivism suggest further avenues for development within CBI, especially in the areas of pattern recognition and speech processing.

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## CBI

CBI is a proficiency-based teaching methodology that seeks to integrate content and language learning through the use of authentic language materials in the classroom. As Stoller and Grabe (1997) note, "Despite differences in theoretical and practical orientations, [approaches] to CBI uniformly view language as a medium for learning content, and content as a resource for learning language" (p. 78). The features that characterize a CBI model include the aforementioned shared focus on content and language (Cammarata, 2010; Grabe & Stoller, 1997; Klahn, 1997; Klee & Tedick, 1997; Shaw, 1997; Stoller, 2004; Stryker, 1997; Stryker & Leaver, 1997; Wesche & Skehan, 2002), a strongly student-centered curriculum (Grabe & Stoller, 1997), and an emphasis on learner autonomy (Cammarata, 2010; Shaw, 1997).

An additional feature of CBI is its emphasis on social interaction and cooperative learning strategies (Grabe & Stoller, 1997; Stoller, 2004; Wesche & Skehan, 2002). CBI recognizes language as a negotiated act requiring conscious involvement on the part of its practitioners. Prioritizing meaningful content serves the dual function of enriching students' academic development in their chosen field while allowing them to co-construct language and meaning. As Cammarata (2010) asserts, "The notion of language as discourse, which considers individuals as agents in the meaning making process and posits that context is central to any meaning making activity, represents the foundation that guides many of the principles at the core of CBI" (p. 93).

Support for CBI as a teaching methodology has come from many camps. Grabe and Stoller (1997) review evidence from several avenues of investigation, including second language acquisition research (especially work by Krashen, Swain, and Cummins), training studies (for example, extensive reading), studies in educational and cognitive psychology, and CBI program outcomes (pp. 6–19). What is needed is an updated account of how CBI fares in a broader understanding of cognition, learning and memory.

## COGNITIVE SCIENCE, CONSCIOUSNESS, AND LANGUAGE

Cognitive science is a collective term for the body of research that addresses long-standing questions regarding the source, development, and deployment of human knowledge (Gardner, 1985, p. 6). Cognitive scientists are specialists in a variety of disciplines, including philosophy, psychology, artificial intelligence, linguistics, anthropology, and neuroscience. They share a belief in the value of interdisciplinary studies (Gardner, 1985, p. 6). To understand how connectionism and constructivism have come to play important roles in cognitive science research initiatives, it is helpful to briefly review the history of cognitive science efforts as a whole.

Alan Turing, a founding father of cognitive science, was interested in the brain's ability to accomplish its work given its structure as a logical system and independent of its status as "spongy tissue made up of a particular kind of biological cell formation" (Hodges, 1983, p.

291). In fact, this objectivist dissociation of function from matter was characteristic of the early days of cognitive science and of cognitivism in general as a working paradigm (Stewart, 2001, pp. 3, 10). Turing's focus on machine logic, that is, his emphasis on codifying and replicating human mental operations, had tremendous influence on the development of the field. As a result, cognitive science grew in close association with advances in computation, thus contributing to the establishment of the computer as the modern day metaphor for cognition (Bialystok & Hakuta, 1994; Gardner, 1985; Stewart, 2001).

By the late 20th century, however, one important shift began to redirect research programs within cognitive science. Brain imaging technology, first developed in the medical field but later co-opted by researchers working in the neurosciences, introduced previously unimaginable levels of access to the brain's topography and dynamic function. The emergence of sophisticated imaging techniques, such as Structural Magnetic Resonance Imaging (sMRI) and Evoked Response Potentials (ERP), enabled researchers to monitor brain activity at high levels of spatial and temporal detail (Coggins, Kennedy, & Armstrong, 2004; Elman et al., 1996; Kennedy, 2006). With the inclusion and expanded use of Positron Emission Topography (PET), Magneto-encephalography (MEG) and functional MRIs (fMRI), it suddenly became possible to precisely identify areas of the brain that are active during a variety of cognitive tasks.

These advances in imaging, especially when combined with equally impressive gains in computer modeling, challenged researchers to reevaluate their linear understanding of the brain's logical function and to consider how the biomechanics of the brain allow it to respond to incoming stimuli. Therefore, the traditional division between function and matter began to erode, creating new avenues for investigating age-old philosophical questions—principal among them, the nature of consciousness. In response to the revived interest in consciousness, investigators across disciplines have increasingly turned their focus to issues related to speech and language. They have noted the uniqueness of speech phenomena as well as its complexity and unrivaled ability to inform on how the brain processes and organizes information. In the next sections, I describe connectionism and constructivism, two frameworks that have been important to the evolution of thought within cognitive science, and I comment on their relevance to first and second language acquisition.

## CONNECTIONISM

Connectionism (also referred to as 'complex network theory,' 'neural network theory,' and 'dynamical systems theory') may be traced back to the eighteenth-century Swiss mathematician, Leonhard Euler, and his original Graph Theory proposal (Papo, 2014). Euler's interest lay in the graphing of small networks (see his famous "Seven Bridges of Königsberg" analysis). In particular, he was concerned with capturing generalizations that would apply to network behavior, such as: how information circulates within the network, how small groups of individual nodes are able to self-organize and form communities of different sizes, and how those different-sized communities then interact with one another.

Modern-day interest in connectionism focuses on larger and more complex networks of all types, though the generalizations that captured Euler's attention remain roughly the same. Rather than viewing cognition as a process of linear rule formation, connectionism relies on the notion that intelligent behavior can be exhibited "without storing, retrieving or otherwise operating on structured symbolic expressions" (Fodor & Pylyshyn, 1988, p. 5). Connectionism's appeal lies in the fact that it can be understood as a biologically-oriented framework for characterizing complex behavior, describing processing as it occurs "via transformations of patterns of activity across large sets of connections" (Joanisse & McClelland, 2015, p. 2). With large networks, it can be difficult to assess the precise number of units. In the case of the human brain, for example, there are over 80 billion neurons (or nodes) with trillions of connections between them. Further, it may be assumed that there is at least as much complexity in the dynamics between units as in the structure itself.

The aims of connectionism are descriptive but also potentially predictive, in that generalities common to all networks emerge, regardless of type. To be considered a network, the system must contain a sufficiently large number of interacting units (in the thousands or millions). Connectionism has advantages over the classic computational view of cognition; specifically connectionism is (a) based on the observed behavior of real-world networks and is also (b) consistent with current information about the actual function of brains (Elman et al., 1996; see Fodor & Pylyshyn, 1988 for an opposing viewpoint). The general principles that govern network behavior are that (a) a network's architecture determines its behavior, and (b) the architecture of a given network is determined by the number and types of units, as well as by the patterns of connectivity between units and the spread of activation (similar to the action of afferent and efferent nerves in the brain). From these rules, global behaviors emerge out of systems that operate on the basis of local interactions.

Of special interest in connectionism are phenomena related to correlated activity. Correlated actions strengthen the pathways between nodes and contribute to a kind of weighting between them. The weighting mechanism, a real-valued number serving to multiply the output of the sending node, is the vehicle through which knowledge is progressively built up in the network (Elman et al., 1996).

Computational modeling has been the main way to test learning in connectionist models. Two well-known examples illustrate how computer simulations have been used to test generalizations specific to language learning: (a) learning the English past tense (Plunkett & Marchman, 1991; Rumelhart & McClelland, 1986), and (b) examining variability in speech and the role of context (McClelland & Elman, 1986). What follows is a brief overview of the design and results of these studies.

The studies addressing acquisition of the English past tense were motivated by the observation that, given the number of irregularities and low predictability based on verb type, the English past tense is notoriously difficult to learn. To test the extent to which an artifical network would be able to successfully generate the past tense of new verbs after exposure to a given number of regular and irregular English verbs, Rumelhart & McClelland (1986) trained a computer model to produce past tense responses for phonological representations of a verb stem. They trained their model on 420 verbs. In the verb stems, each of the input neurons was considered to represent some phonetic feature of the verb. The activation pattern on the output units was then compared to the target activation pattern (i.e., the correct phonological representation of the past tense of the verb). In the case of discrepancies between the actual output pattern and the target output, an error signal was sent to the learning algorithm to prompt adjustments to the connections in the network.

In their findings, Rumelhart and McClelland (1986) reported that the network was able to produce correct past tense forms for the majority of the verb stems to which it was exposed. Network performance on any particular verb was shown to be influenced by a complex interaction of the token frequency, the number of verbs in the same sub-class, the degree to which features were shared with other sub-classes, and the phonological characteristics of the verb (Plunkett & Marchman, 1991; Rumelhart & McClelland, 1986). An interesting phenomenon observed in the course of this experiment was that the model at one point in the training produced a large number of over-regularization errors, thus mirroring observed behavior in child language development (Joanisse & McClelland, 2015, p. 7). With further training, the model recovered and was able to resume predicting regular and irregular past tense forms with its former accuracy.

A second model of language learning, the TRACE model in speech perception, addressed the issue of variability in speech and the role of context. This model highlights an important contribution that connectionism brings to theories of language learning: an account of the interaction between bottom-up sensory information and top-down contextual/experiential information (Joanisse & McClelland, 2015, p. 2). The TRACE model uses different layers of nodes to represent auditory, phonemic, and word-specific information (Joanisse & McClelland, 2015, p. 3). Word recognition is simulated by subjecting inputs to these three layers of analysis. A key characteristic of the model is that the auditory input changes over time. Furthermore, the model is interactive in that nodes activated from above can influence those below and vice versa. In the area of lexical effects, findings from the TRACE model showed that the lexicon provides a strong top-down influence on perception, which is able to compensate for degraded or missing input. Bottom-up influence showed that the sound sequences in non-words like "bliffle" were processed much better than those whose sound combinations were less common, like "dliffle". Therefore, the model shows how processing at the auditory or feature level may contribute to the establishment of phonotactics in a language and predict the viability of new words. Overall findings of the TRACE model indicate that context influences processing at all levels (McClelland & Elman, 1986).

## CONSTRUCTIVISM

Where connectionism addresses the inner life of networks, constructivism describes the role played by input in the structuring of thought. As a metatheoretical perspective that seeks to explain the epigenetic factor in learning, constructivism examines how the environment and one's actions within that environment translate into consciousness. The precise origin of constructivism in philosophy is under dispute. Donald (2001) attributes the development of the framework to Condillac, an eighteenth-century French philosopher. Others claim that the idea can be traced back to Plato. Many practitioners in foreign language education will be familiar with constructivism through its offshoot, social constructivism, a community-oriented version of constructivism that is heavily influenced by the writings of the early twentieth-century psychologist, Lev Vygotsky. Social constructivism diverges from constructivism in positing that meaning comes into existence through one's interactions with other people.[1]

In general, constructivist models represent learning as a negotiation between the outside world ("environment" or "context") and the individual's ability to compare exemplars, to form categories, to generate and test hypotheses. Consciousness in the individual emerges in the nexus between memory, attention, and the environment. Donald (2001) notes:

[1] As one reviewer pointed out, however, Vygotsky himself emphasized the importance of intrapsychic processes, specifically mentioning "egocentric speech" as a bridge between internal and external (or "social") speech (Vygotsky, 1978, p. 27).

> Attention determines the sequential flow of memory fixations and perceptual comparisons, and these determine the precise quality and sequencing of subjective experience, producing unique juxtapositions in the mind's eye and influencing what habits we form and what interpretation we place on events. (p. 228)

According to this viewpoint, attention and voluntary imagery do not emerge fully formed. Rather, they must be configured and exercised through experience over the course of an individual's lifetime (Donald, 2001; Kennedy, 2006).

This suggests that the richness and nature of experience play an outsized role in development, an idea that has been corroborated in research on the brain. Kennedy (2006) notes, "Enriched experiences enhance neural growth and thus enhance learning, indicating that brains construct themselves through life experiences" (p. 473). A similar concept was expressed by Vygotsky in the early part of the twentieth century. He wrote about the interconnectedness of children's speech development and action, suggesting that the two are "part of *one and the same complex psychological function*, directed toward the solution of the problem at hand" (Vygotsky, 1978, p. 25). Vygotsky surmised that the use of tools in combination with speech invoked psychological functions related to perception, sensory-motor function, and attention. He considered all of these functions to be integrated in one "dynamic system of behavior" (p. 31).

In research on speech, many investigators have focused on the perception of sounds in the environment and the role this plays in speech production. Kuhl's seminal work on the perceptual-motor link showed that perception influences production at early stages of development, concluding that, "Experience warps the perceptual space underlying speech" (Kuhl, 1994, p. 812). If it is true that experience strongly influences how information is processed, we may expect substantial variability from one individual to the next in the way learners receive and assimilate information. Indeed, Christiansen and Chater (2008) report individual differences in sentence processing abilities in groups of college students that otherwise appear homogenous. They attribute these differences to "underlying variations in learning and processing mechanisms combined with variations in exposure to language" (p. 506).

## Example of Word Learning

To understand how the frameworks of connectionism and constructivism complement one another in language acquisition, it is helpful to consider the example of word learning. We now know that learning based on the frequencies and distributions of events in the environment is a key aspect of cognitive development (Denison & Xu, 2012; Ellis, 1998; Kennedy, 2006; Lythgoe, 2006; Seidenberg, 1997; Tenenbaum, 1999; Xu & Griffiths, 2011). Human infants appear to be born with the ability to perform sophisticated frequency analyses (Bosch, 2010; Denison & Xu, 2012; Kuhl, 1994). Bosch (2010) showed that from two months of age an infant is able to track the statistical properties of sound patterns in her native language and differentiate that language from others.

For the young child, the process of word learning is *implicit*; it is independent of any overt knowledge of either the process of acquisition or the target knowledge base (Kuhl, 1994; Winter & Reber, 1994). Instead, the young child (like the adult) will learn most of the words he or she knows through context (Bloom, 2000; Sternberg, 1987; Tenenbaum & Xu, 2007), using general learning processes of inference and hypothesis testing (Winter & Reber, 1994, pp. 117–118).

An example from psycholinguistics demonstrates how inference about events in the environment plays an important role in the construction of word meaning. As Seidenberg (1997) has shown, ambiguities in word meaning can be resolved through probabilistic constraints derived from one's previous experience with language and the world (p. 1601). In English, the phones [plɛɪn] and [lɛft] are ambiguous insofar as both have multiple common meanings involving different parts of speech. For example, we can "plane" a piece of wood (verb) or hang a "left" (noun). Nonetheless, the combination of [plɛɪn] and [lɛft] in a sentence makes it very likely that the first word represents an airplane (noun) and the second represents the past tense of "leave" (verb).

The learner draws on information from surrounding words in order to infer context and construe meaning (Christiansen & Chater, 2008; Lewis-Kraus, 2015; Tenenbaum & Xu, 2007). Connectionism provides a mechanism by which meaning and structure can be extracted from even a limited number of examples relying on the power of distribution and patterns of activation.

> The connectionist paradigm has provided vivid illustrations of ways in which global behaviors may emerge out of systems which operate on the basis of purely local information. A number of simple but powerful learning algorithms have been developed which allow these networks to learn by example. What can be learned (without being prespecified) has been surprising, and has demonstrated that a great deal more information and structure is latent in the environment than has been realized. (Elman et al., 1996, p. 4)

How does participating in a system affect the understanding of a word? For Vygotsky (1986), "A word in context means both more and less than the same word in isolation: more because it acquires new context; less, because its meaning is limited and narrowed by the context" (p. 245). He perceived word meanings as dynamic rather than static formations, changing along with the developing child and his or her variations in thought (p. 217). In connectionist terms, a crucial component of learning is the reinforcement of certain neural pathways and the consequent exclusion of others. Which pathways are strengthened and which are left idle is represented as a function of experience.

Back in the 1930s, Vygotsky (1978) wrote about "two qualitatively different lines of development, differing in origin" (p. 46). The first line represented elementary processes, biological in origin. The second line represented "higher" psychological processes (my emphasis), which were sociocultural in origin. Cognitive science, despite decades of purposefully averting its attention away from this second line of inquiry (Gardner, 1985), has begun to reconsider the question of cognition as a sociobiological phenomenon. Hence, Elman et al.'s (1996) suggestion that knowledge be represented as "epigenetic," an outgrowth of the interaction between nature and nurture.

A main criticism voiced by Vygotsky toward his contemporary, Piaget, was that the latter's theory of cognitive development failed to bridge the gap between structural and functional approaches (Vygotsky, 1986, p. 207). Vygotsky believed that the most interesting questions surrounding cognition lay exactly in the intersection between environment and biology. Some 80 years later, many modern cognitive scientists agree that issues related to development and instruction can best be reconciled by considering that "what" functions determines to a certain extent "how" it functions.

## EXTENSION OF CONCEPTS AND IMPLICATIONS FOR PEDAGOGY

In the previous sections, an overview of connectionism and constructivism was given, describing how the frameworks apply to cognition in general and to word learning in particular. The following section will detail the ways in which CBI models of foreign language instruction draw on the precepts of connectionism and constructivism to address challenges posed by language learning. Consider the following challenges, viewed from the perspective of neuroscience (Lythgoe, 2006):

- *Deep context*: In addition to the more tangible actions and reactions experienced in daily life, languages reference a long history of events and cultural norms. The individual with little experience in the target culture must learn to map sounds and groups of sounds to concepts of which he may have only a nascent understanding (see also Vygotsky, 1986).

- *Complexity on different levels (phonemic, syllabic, morphological, lexical, syntactic, pragmatic, etc.)*: The recursive (or nesting) property of language has been described as a main differentiator between human language and systems of acoustic communication found in other species. Human languages embed linguistic units of variable sizes. Each unit is in turn governed by its own set of rules and interactions. The language learner must determine how all of these interlocking parts work together in order to understand and produce speech.

- *Simultaneous demands on attention and working memory*: The individual must selectively attend to speech sounds as she monitors the environment, know when she is expected to react, and know how to react appropriately.

- *Rate of speech*: Average speech production has been estimated at roughly 15 consonants and vowels per second (MacNeilage, 2008, p. 3). This represents the fastest of all complex human behaviors, posing challenges for both production and perception.

The next sections will review how CBI addresses these challenges by drawing on principles of connectionism and constructivism.

### CBI as a collaborative social endeavor

CBI thrives as a collaborative social endeavor, reflecting the interactive nature of language itself (Grabe & Stoller, 1997; Stoller, 2004; Wesche & Skehan, 2002). Ideally, a foreign language curriculum for adult learners rivals real-world scenarios in depth and complexity. Constructivists maintain that a stimulus-rich environment is critical to learner success. Further, they believe that the same mechanisms involved in acquiring language will be deployed when using it (Seidenberg, 1997). The idea that one continues to exercise the strategies that first contributed to learning ties into the notion of language proficiency. Bialystok and Hakuta (1994) note:

> Proficiency depends on use. If language is needed to navigate the streets of a new country, then social and communicative knowledge, a particular vocabulary, and some fluency are at the top of the proficiency list. If language is needed to read academic documents in a foreign language, then grammar and literacy become more important. Proficiency is what you need to do with the language, and the Good Language Learner is the person who finds the right skills to achieve a particular proficiency.[2] (pp. 158–159)

In terms of social organization, many CBI classrooms differ from traditional learning models in their preference for small group work and cooperative learning activities (Grabe & Stoller, 1997; Stoller, 2004; Wesche & Skehan, 2002). These features allow the individual learner to practice communicative skills and relationship building in the target language. In addition, working in small groups provides an opportunity to examine cultural differences in a safe context, with known interlocutors. Further, each group member can potentially contribute to and draw on the knowledge of the group as a whole, thus compounding the number of inputs.

## Procedural versus declarative knowledge

Perhaps the most fundamental difference between CBI and other foreign language teaching methodologies is CBI's emphasis on procedural versus declarative knowledge. I illustrate this point with a passage from *Genius: The life and science of Richard Feynman*, in which the renowned physicist reflects back on a childhood argument:

> I said, 'I haven't the slightest idea what kind of bird it is.' He says, 'It's a brown-throated thrush. Your father doesn't teach you anything!' But it was the opposite. He had already taught me: 'See that bird?' he says. 'It's a Spencer's warbler.' (I knew he didn't know the real name.) 'Well, in Italian, it's a *Chutto Lapittida*. In Portuguese, it's a *Bom da Peida*. In Chinese, it's a *Chung-long-tah*, and in Japanese, it's a *Katano Tekeda*. You can know the name of that bird in all the languages of the world, but when you're finished, you'll know absolutely nothing whatever about the bird. You'll only know about humans in different places and what they call the bird. So let's look at the bird and see what it's *doing*- that's what counts. (Gleick, 1992, p. 29)

In a CBI classroom, just as with the brown-throated thrush, the focus is shifted from what the words *are* to what they're *doing*. That's what counts. Students new to CBI often enter the language classroom with the assumption that once they memorize all of the vocabulary and verb conjugations, they will "know" (i.e., be able to speak) that language. (Little do they realize that native speakers of a language typically know tens of thousands of words.) Memory does play a large part in natural language learning, but rote memorization does not. In fact, for memory to be effectively engaged, students must be able to link words to context (Bloom, 2000; Kennedy, 2006; Sternberg, 1987; Tenenbaum & Xu, 2007). Repetition is an

[2] This view of proficiency is reinforced by research on neural plasticity, the brain's ability to develop new structures in response to changes in behavior and/or the environment. Adult brains are now credited with a much greater malleability than was thought in previous decades (Coggins, Kennedy, & Armstrong, 2004; Diamond, 2001; Elman et al., 1996; Kennedy, 2006; Mallucci, 2015).

important factor for learning as well (Ellis, 2013; Kennedy, 2006). Content-based design that features many different learning activities structured around a central theme exposes students to vocabulary without resorting to the use of lists. Instructors do not have to look for authentic learning materials that repeat the use of certain words. Rather, by selecting materials along a similar theme, the same words tend to re-emerge (naturally).

This last point serves as a valuable reminder that language functions as a *system*, displaying exactly the same properties previously described for networks. Understanding the system (or network) requires an awareness of the *frequency* with which items (in this case, words) appear, as well as the *patterns of activation* between them. Attention to the details of co-occurrence is a first step to integrating new items into the learner's working knowledge of the language. The ability to discern patterns not only cuts down on the amount of information that must be remembered; it also brings language dynamics (i.e., what is frequent, possible, occasional, ubiquitous, etc.) to the forefront. A focus on patterns directs learner attention to *how the language is used*. The formulation and discussion of ideas about language use in the CBI classroom contributes not only to the learner's understanding of the target language at different stages of development but also to his or her ability to accurately frame original utterances in the target language.

## Nonlinearity of system learning

A recognized feature of system learning is its nonlinearity (Brooks & Brooks, 2001). This feature is predicted by connectionist models based on the nature of interactions between nodes. (Recall that the pathways between nodes become strengthened or weakened over time and as a function of variable inputs.)

This implies that in order to master a system, one needs time and a sufficient number of varied inputs. Curricula in CBI are not structured in a linear fashion with regard to language development. They may be organized according to a progression of topics related to content, but there is no pre-planned sequence of language issues to "cover." Therefore, there are no a priori expectations of what grammar, for example, students will have internalized by the end of the course. Grammar is of interest in that (a) its supposed "acquisition" in non-CBI classrooms is often used as a benchmark of student progress and (b), although grammar ≠ language—the network of language being so much more than its observable output (also see Christiansen & Chater, 2008)—the acquisition of grammar is nevertheless emblematic of the nonlinear learning experience. Young children require years to fully master the grammar system of their native language. As Donald (2001) remarks:

> Grammar is hard won, even with intensive enculturation. Before its rules can be learned, they must be found. To find them, the mind must be able to split its attention, use its imagination, and test its conclusions, over and over, spinning off memories at a dizzying rate and storing away what it learns in a form that can be easily recalled. (p. 249)

The connectionist framework is useful in its ability to capture learner capabilities at various stages of development and to show how these change over time, often displaying a period of backsliding before the system has been acquired (Joanisse & McClelland, 2015, p. 11).[3] Connectionism supports CBI in that the latter does not seek to establish arbitrary and unattainable guidelines for grammar or other (aspects of) language acquisition.

## Emphasis on processing

The emphasis in CBI courses is on processing and use. Speech processing in real time requires the learner to extract and analyze discrete elements as they flash by, disguised in complex temporal sequences. Successful speech processing shares many attributes with sequential learning, most notably a reliance on planning and motor control (Christiansen & Chater, 2008, p. 502).[4] The importance of sequential learning has been demonstrated for a variety of skills related to speech processing, including: speech segmentation, the locating of prosodic boundaries, the integration of phonological and distributional cues, the detection of long-distance relationships between words, etc. (Christiansen & Chater, 2008, p. 502).

## Focus on the individual and group dynamics

The curricula in CBI courses are normally designed around the students' academic and/or professional interests (Grabe & Stoller, 1997). A major way in which CBI differs from other foreign language teaching methodologies is that the instructor creates the curriculum herself (rather than teaching from a textbook). Therefore, the curriculum also reflects the instructor's interests and background to some extent.

Once the course begins, the role of the instructor becomes that of guide, facilitator, and coach (cf. Brooks & Brooks, 2001). Though all adults have experienced learning at least one language (i.e., their own), few remember the process. Therefore, they must be reoriented to language learning in the foreign language classroom. Through the use of activities and assignments, the CBI instructor creates an opportunity for learners to engage with the target language in ways that will build proficiency.

CBI places a high premium on dialogue between all members in the classroom (cf. Brooks & Brooks, 2001). In many CBI classrooms, students take an active role as co-contributors to the curriculum, either by suggesting topics or by engaging the class as experts on a given topic. Because so much of the curriculum evolves in response to the needs of the group, both in terms of content and in terms of language development, one very important role of the CBI instructor is that of listener/observer. Effective CBI instructors constantly monitor the pulse of the class, gauging the students' response to the content and observing their interaction with it.

In a 2009 interview, Howard Gardner remarked that all education is essentially concerned with transfer. While transfer (of skills in FL education) may be the primary *objective* of

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[3] The phenomenon of nonlinearity is represented in this article as an outcropping of system learning predicted by the principles of connectionism. I am grateful to one reviewer for pointing out that other recent viewpoints in SLA (most notably, language ecology and complexity theory) also highlight the issue of nonlinearity but discuss it in terms of how language learning changes over time in response to primarily *sociocultural* pressures. This view is not inconsistent with the account of connectionism (and related principle of nonlinearity) given here. While it is certain that the nature and extent of the social pressures affecting language acquisition will be of primary interest to FL researchers, addressing these topics in detail goes beyond the scope and aims of the present article.

[4] The term "sequential learning" here refers to learning associated with the serial ordering of complex action sequences. It should not be confused with rule-based learning.

education, the *practice* of pedagogy is concerned with the timely sharing of information (see also Vygotsky, 1986). The fluidity of instruction in CBI emerges in response to a strong sense of timeliness. It is timeliness in the sense of identifying the appropriate amount of knowledge to impart at given stage of learning (as in Vygotsky's Zone of Proximal Development). However, there is also a timeliness of recognizing that a certain group of people has come together in a dedicated space for a dedicated increment of time in order to highlight a particular problem or set of problems. The CBI instructor does not control all of the factors influencing this interaction, nor should she try to do so. However, in recognizing and validating the potential in a given situation, she can do her best to establish the conditions under which, if learning is going to happen, it will.

### Opportunities for further development

A connectionist/constructivist framework suggests areas where CBI methodology could be further developed, namely in the areas of pattern recognition and speech processing. Inevitably, the use of authentic materials in CBI opens up a wide testing ground for examining the many kinds of structures used in language. Connectionism and constructivism suggest a classroom design that not only provides rich linguistic input through the use of authentic materials; it also expands the learning experience by directing students' attention to how units of language may be combined and recombined for the purpose of conveying ideas. Increased focus on pattern recognition would serve to bolster CBI's emphasis on language use. Attention to linguistic detail is not a skill that should be restricted only to linguists. Rather, pattern recognition and critical thinking capabilities are essential to the development of proficiency in a foreign language system.

Similarly, CBI as a FL teaching methodology would benefit from a concentrated effort to address the issue of speech processing. Speech processing must not be confused with "listening comprehension," a task aimed at listening for answers to a pre-selected set of questions. Instead, speech processing refers to how listeners interpret, understand, and act upon speech signals. Teaching activities that target speech processing might involve speech segmentation, the identification of intonation patterns, the use of fillers, etc. CBI's intent to address language learning collaboratively, through a shared focus on authentic and meaningful content, is well founded but underspecified. If CBI is to grow and attract new adherents, its mandates must be expanded to emphasize pedagogical practices that account for details of language processing and use.

## CONCLUSION

CBI addresses many of the challenges known to face language learners. The issue of deep context is addressed by CBI as a collaborative social endeavor, by its emphasis on processing and use and by its focus on both individual and group dynamics. These features of CBI are closely aligned with a constructivist view of knowledge as being something that is crafted by the individual in response to events in the environment.

The issues of complexity on different levels of analysis, simultaneous demands on attention and working memory and rate of speech are addressed by the CBI emphasis on processing and use, on fostering procedural over declarative knowledge, and by the CBI embrace of nonlinearity. The chief problems associated with language learning are predicted by connectionism. Given the inherent complexity of large networks, it is assumed that, where a network is composed of interrelated units numbering in the thousands to tens of thousands, time and a great deal of exposure will be needed to achieve a level of performance consistent with mastery. Connectionism and constructivism justify the practices most closely identified with CBI as supportive of the knowledge acquisition process in general and tailored to system learning in particular.

Cognitive science initiatives have been responsible for many exciting and important advances over the past 75 years. The field has changed very quickly, even within the past decade. A spirit of collaboration and willingness to consider the study of the mind from a variety of perspectives has contributed to the growth of cognitive science as an interdisciplinary enterprise. For FL enthusiasts, it will be useful to periodically review how FL acquisition as a discipline fits into the larger context of cognitive science and how FL teaching methodologies align with a modern understanding of systems, learning, and memory.

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