CENTER FOR
LANGUAGE SCIENCE

PennState
College of the Liberal Arts

BILINGUALISM MATTERS
AT PENN STATE

Newsletter

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# Letter from the Editors

Dear Center for Language Science and Bilingualism Matters friends and colleagues,

This issue of our Center for Language Science (CLS) and Bilingualism Matters at Penn State Newsletter explores the topic of network science. You are most likely familiar with the concept of networks—your own social networks, family networks, school and career networks form an integral part of your daily lives and shape how you navigate the world each day. But you may not have thought about how networks can also exist in your mind, and beyond that, how these mental networks may influence how you think, and possibly even how you use and understand language. In this issue we delve into some of the ways that language scientists have used the concept of networks to understand how we learn, use, and comprehend language. We hope you will find it to be an interesting and accessible window into this exciting and up-and-coming area of language science. You may even find some connections to your own experience with language, or things you've observed or wondered about in your own life. If so, please share them with us! As always, we welcome your questions, comments, ideas, and feedback, and we thank you for your continued interest in the wonderful and expansive world of language science.

Sincerely,

Frances Blanchette, Catherine Pham (editor-in-chief),
Allison Link, Hannah Merseal and Jie Yan

# FEATURED RESEARCH

## Using Networks to Understand Language Learning

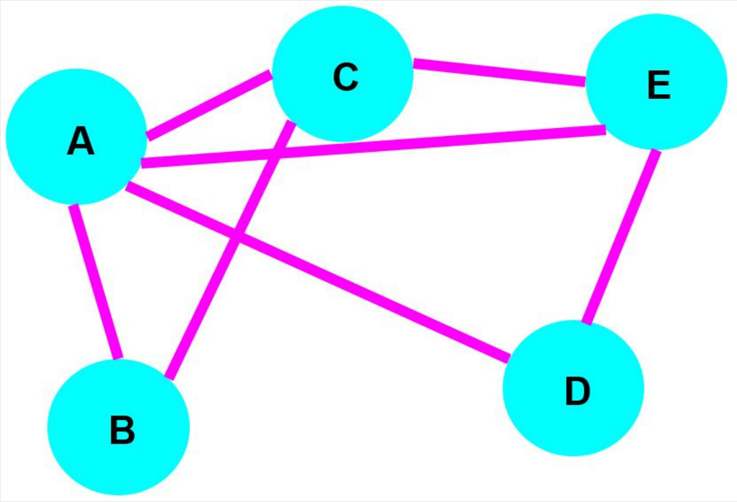
By Hannah Merseal and Catherine Pham

We live in a highly interconnected, complex world. From the global supply chain to the groups of friends and colleagues we interact with day-to-day—to the brain areas and cognitive processes underlying human thinking—we are constantly surrounded by complex, multidimensional systems. Network science approaches, which are based in something called mathematical graph theory, provide researchers with a powerful way to study the variety of complex systems in our world, by modeling them as networks[1,2].

Due to recent and rapid developments in powerful computing, network science approaches have become more accessible than ever. Indeed, in the last twenty years, network science methods have been increasingly applied to analyze complex systems across diverse research areas[3] including transit[4], public utilities[5], sports[6], medicine[7], bioinformatics[8], innovation[9], neuroscience[10], music[11], and human cognition[12,13,14]. The ongoing "network science revolution" in the cognitive sciences has changed the way the field studies a number of topics[15], including the study of knowledge[16], mental disorders[17], aging[18], creativity[19], and learning[20]. In this research summary, we'd like to share with you some insights from a particularly fruitful area of network science research: language learning.

First, what is a network?

A network consists of nodes (the blue circles in the picture to the right) and edges (the pink lines). Nodes represent items that a researcher wants to study. They could be individuals, cities, subway stops, or even words. The relationships between nodes are represented by the edges connecting them. As an example, let's pretend that each node in our image represents a student in a fifth-grade class, and the edges connecting them represent friendships. Student A is quite popular: they are friends with students B, C, D, and E (as can be seen from the edges connecting them to each other student). Student D, by contrast, is only friends with students A and E (perhaps they are newer to the class).




Network science has also been applied to the study of language learning. Children learn words in distinct patterns. More frequently encountered words are learned earlier than less frequently encountered words[21]. However, beyond these frequency effects, what other factors may affect word learning?

One type of relationship that researchers have examined is the relationship between word meanings. For example, if someone is given the cue word dog, another word that might come to mind is cat. Therefore, if dog and cat are two nodes in a network, an edge would be drawn between these nodes because they are related in meaning. Words that are related in meaning to each other are connected to one another to create a "semantic" network. One common method of using networks to understand meaning relationships between words is by considering the number of possible associations between words[22].

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Using powerful computational tools, researchers are able to study large networks by examining every possible combination of two nodes, and whether those nodes are connected by an edge. They can also represent the strengths of connections (perhaps dog and cat are more strongly related than dog and mouse) and directionality of relationships (perhaps the word squirrel comes to mind when given the cue word dog, but dog does not come to mind when given the cue word squirrel). Researchers can calculate many properties of the network, such as whether a node (e.g., word) is connected to many or few other nodes, whether nodes group together into smaller communities, and how easy it is to travel from one node in the network to another node based on the connection between nodes.

Applying these methods to the study of word learning in children, researchers have found that the underlying structure of the language input children receive has an influence on word learning. Words in a network that exhibit a greater number of meaning-based connections to other words are acquired earlier in development than less connected words[23]. These findings have been observed across ten different languages[24]. Additionally, semantic associations between words have been shown to largely explain patterns of word learning at later stages of learning in young children after twenty-three months of age[25]. The distance between words in a network is also an important factor, with distantly related words often acquired earlier than closely related words in semantic networks[26].

The field of network science has revolutionized the way researchers have approached the study of language learning as a whole. While the present article focuses on contributions of semantic networks to the study of word learning, the tools of network sciences can and have been implemented across a broad range of topics. Check out our interview with Roger Beaty, Michele Diaz, and Chaleece Sandberg to learn more about the various ways researchers at Penn State are using network science to address a variety of language-related research questions.

References


1. Barabási, A.-L. (2016). *Network Science*. Cambridge University Press.
2. Newman, M. (2018). *Networks*. Oxford University Press.
3. Vespignani, A. (2018). “Twenty years of network science,” *Nature*, 558, 528–529. https://doi.org/10.1038/d41586-018-05444-y
4. Latora, V. & Marchioni, M. (2002). “Is the Boston subway a small-world network?” *Physica A: Statistical Mechanics and its Applications*, 314(1:4), 109–113. https://doi.org/10.1016/S0378-4371(02)01089-0
5. Tu, H., Xia, Y., Iu, H. H., & Chen, X. (2019). “Optimal robustness in power grids from a network science perspective.” *IEEE Transactions on Circuits and Systems II: Express Briefs*, 66(1), 126–130. https://doi.org/10.1109/TCSII.2018.2832850
6. Buldú, J. M., Busquets, J., Echegoyen, I., & Seirul-Lo, F. (2019). “Defining a historic football team: Using network science to analyze Guardiola’s F. C. Barcelona.” *Nature: Scientific Reports*, 9, 13602. https://doi.org/10.1038/s41598-019-49969-2
7. Lee, U. & Mashour, G. A. (2018). “Role of network science in the study of anesthetic state transitions.” *Anesthesiology*, 129, 1029–1044. https://doi.org/10.1097/ALN.0000000000002228
8. Oulas, A., Minadakis, G., Zacharious, M., Sokratous, K., Burdakou, M. M., & Spyrou, G. M. (2017). “Systems bioinformatics: Increasing precision of computational diagnostics and therapeutics through network-based approaches.” *Briefings in Bioinformatics*, 20(3), 806–824. https://doi.org/10.1093/bib/bbx151
9. Fabrizi, A., Guarini, G., & Meliciani, V. (2018). “Green patents, regulatory policies, and research network policies.” *Research Policy*, 47(6), 1018-1031. https://doi.org/10.1016/j.respol.2018.03.005
10. Bassett, D. S. & Sporns, O. (2017). “Network neuroscience.” *Nature Neuroscience*, 20, 353–364. https://doi.org/10.1038/nn.4502
11. Merseal, H., Beaty, R. E., Kenett, Y. N., Lloyd-Cox, J., de Manzano, Ö., & Norgaard, M. “Representing melodic relationships using network science.” *SSRN*. https://dx.doi.org/10.2139/ssrn.4124961
12. Baronchelli, A., Ferrer-i-Cancho, R., Pastor-Satorras, R., Chater, N., & Christiansen, M. H. (2013). “Networks in cognitive science.” *Trends in Cognitive Sciences*, 17(7), 348–360. https://doi.org/10.1016/j.tics.2013.04.010
13. Karuza, E. A. (2022). “The value of statistical learning to cognitive network science.” *Topics in Cognitive Science*, 14(1), 78–92. https://doi.org/https://doi.org/10.1111/tops.12558
14. Siew, C. S. Q., Wulff, D. U., Beckage, N. M., & Kenett, Y. N. (2019). “Cognitive network science: A review of research on cognition through the lens of network representations, processes, and dynamics.” *Complexity*, 2108423. https://doi.org/10.1155/2019/2108423
15. Kenett, Y. N., & Hills, T. T. (2022). “Editors' introduction to networks of the mind: How can network science elucidate our understanding of cognition?” *Topics in Cognitive Science*, 14(1), 45–53. https://doi.org/https://doi.org/10.1111/tops.12598
16. De Deyne, S., Kenett, Y. N., Anaki, D., Faust, M., & Navarro, D. (2017). “Large-scale network representations of semantics in the mental lexicon.” In M. N. Jones (Ed.), Big data in cognitive science (pp. 174–202). Routledge/Taylor & Francis Group.
17. Robinaugh, D. J., Hoekstra, R. H., Toner, E. R., & Borsboom, D. (2020). “The network approach to psychopathology: a review of the literature 2008–2018 and an agenda for future research.” *Psychological medicine*, 50(3), 353–366. https://doi.org/10.1017/S0033291719003404
18. Cosgrove, A. L., Kenett, Y. N., Beaty, R. E., & Diaz, M. T. (2021). “Quantifying flexibility in thought: The resiliency of semantic networks differs across the lifespan.” *Cognition*, 211, 104631. https://doi.org/10.1016/j.cognition.2021.104631
19. Kenett, Y. N., & Faust, M. (2019). “A semantic network cartography of the creative mind.” *Trends in Cognitive Sciences*, 23(4), 271–274. https://psycnet.apa.org/doi/10.1016/j.tics.2019.01.007
20. Karuza, E. A., Thompson-Schill, S. L., & Bassett, D. S. (2016). “Local patterns to global architectures: Influences of network topology on human learning.” *Trends in Cognitive Sciences*, 20(8), 629–640. https://doi.org/10.1016/j.tics.2016.06.003
21. Goodman, J. C., Dale, P. S., & Li, P. (2008). “Does frequency count? Parental input and the acquisition of vocabulary.” *Journal of child language*, 35(3), 515–531. https://doi.org/10.1017/S0305000907008641
22. Steyvers, M., & Tenenbaum, J. B. (2005). “The large-scale structure of semantic networks: Statistical analyses and a model of semantic growth.” *Cognitive Science*, 29(1), 41–78. https://doi.org/10.1207/s15516709cog2901_3
23. Hills, T. T., Maouene, M., Maouene, J., Sheya, A., & Smith, L. (2009). “Longitudinal Analysis of Early Semantic Networks: Preferential Attachment or Preferential Acquisition?” *Psychological Science*, 20(6), 729–739. https://doi.org/10.1111/j.1467-9280.2009.02365.x
24. Fourtassi, A., Bian, Y., & Frank, M. C. (2020). “The Growth of Children’s Semantic and Phonological Networks: Insight From 10 Languages.” *Cognitive Science*, 44(7), e12847. https://doi.org/10.1111/cogs.12847
25. Stella, M., Beckage, N. M., & Brede, M. (2017). “Multiplex lexical networks reveal patterns in early word acquisition in children.” *Scientific reports*, 7(1), 1–10. https://doi.org/10.1038/srep46730
26. Engelthaler, T., & Hills, T. T. (2017). “Feature biases in early word learning: Network distinctiveness predicts age of acquisition.” *Cognitive Science*, 41, 120–140. https://doi.org/10.1111/cogs.12350

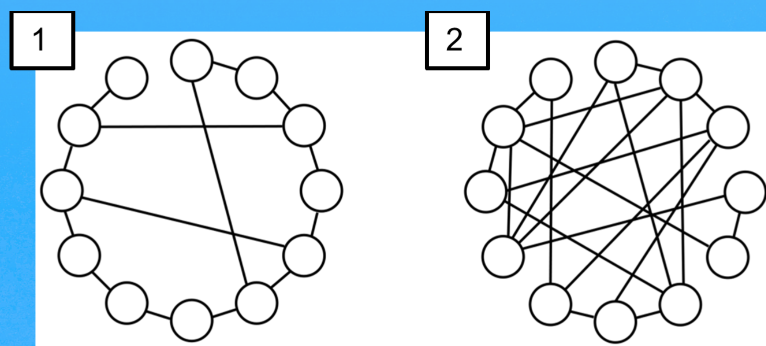
# Spot the Difference!

## Illustrating Network Properties

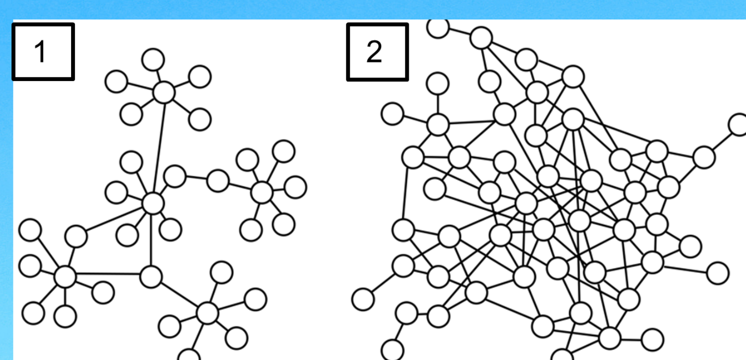
By Allison Link

In network science, there are certain properties that can be observed across many different kinds of networks. Whether they are examining social networks or biological networks, researchers use these properties to understand the interactions between nodes. Below are several pairs of network graphs. In each pair, one of the graphs shows the presence of a specific network property and the other shows the absence of that same property. Try out your network science skills by seeing if you can spot the different relationships between nodes. Then, read the blurb to learn more about each property and find out whether you guessed correctly!

These two network graphs represent differences in small-worldness. Graph 1 represents a small-world structure: most of the nodes do not have direct connections with each other, but distant nodes can be reached by "traveling" along a small number of edges. A real-world example of this can be seen in social networks, where two strangers can often be linked by one or two shared acquaintances. Graph 2 does not have small-world structure, as each node is directly connected to many other nodes within the network. Generally speaking, small-world networks are more efficient as the average "path" between nodes is shorter.




The degree of a node refers to the number of connections it has with other nodes. High-degree nodes share lots of connections, while low-degree nodes may only be connected to a few nodes. Assortativity is a feature of networks where nodes that are similar in degree tend to be connected. Graph 2 in this pair is an assortative network, since low-degree nodes are connected to other low-degree nodes (this can be seen at the edges of the network), and high-degree nodes are connected to each other (this can be seen in the middle of the network). Graph 1 is disassortative, since many low-degree nodes are connected to a single high-degree node. This is represented by the branch-like connections throughout the graph. A real-world example of a disassortative network is the interactions between job recruiters and people seeking employment. Recruiters interact with many potential applicants for a job, whereas those applicants are unlikely to be interacting with each other.

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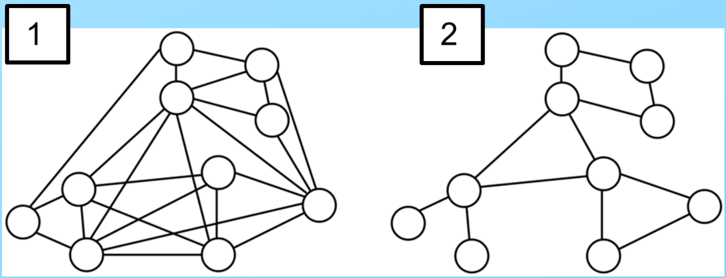
While both of these graphs have the same number of nodes, they differ in their community structure. This refers to the presence of communities, which are groups of nodes that share connections within their group but have few connections outside of it. Graph 2 has community structure, since there are several modules that are sparsely connected to each other. Graph 1 does not have a strong community structure since its nodes are well connected and lack distinct modules. We often seen this kind of structure in metabolic networks, where modules represent different pathways or cycles that occur within a biological cell.




# Events

During the fall semester, we participated in the State College Area School District's English as Second Language (ESL) Potluck event. CLS graduate research assistants, Jie Yan, Catherine Pham, and Hannah Merseal, shared information and engaged families in games and activities to raise awareness about the science of multilingualism, and they enjoyed some delicious international cuisine while they were at it!


# FEATURED PARTNER

## Meet some network scientists!

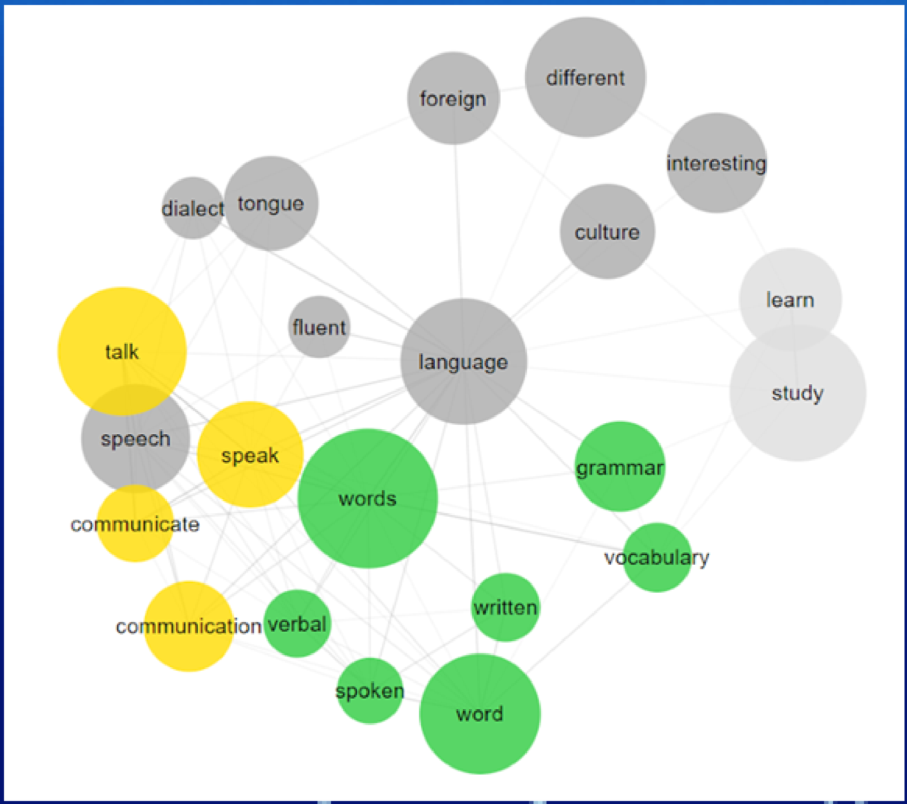
Interviews by Jie Yan

**Michele Diaz**

**Chaleece Sandberg**

**Roger Beaty**

We are all members of our own social networks. We're connected to the people we know, who may or may not be connected to each other. And the people we know also know other people, who we ourselves are not connected to directly. This type of network of relationships can be a useful way to think about many aspects of the world, including language. The illustration to the right, provided by one of our featured partners Roger Beaty, shows how our knowledge of words can be understood as a sort of network in our minds.



**For this installment of our featured partner piece, we interviewed several CLS faculty who use network science in their own research: Michele Diaz, professor of psychology and linguistics, who studies language and aging; Chaleece Sandberg, associate professor of communication sciences and disorders, whose interests center around language disorders and bilingualism; and Roger Beaty, assistant professor of psychology, who investigates creativity. Their responses provide an interesting window into how using networks like the one above can help us learn about a wide range of topics in language science.**

## In your research, you have used network science. Could you explain for our readers what that is?

"Network science is a set of tools that allows you to look at how things are related to one another. It can be applied to any number of fields and situations: looking at social relations among individuals, how planes fly between airports, or how words are connected via semantic (meaning), phonological (sound), orthographic (written form), or other linguistic links."

"Network science is the study of any system that can be represented as a network of interconnected objects. For example, in a social network, each person is a node in the network and relationships between people serve as the links that connect the nodes into a network form. I mainly study functional brain networks in which brain regions serve as the nodes, and similarity in their activation patterns over time serve as the links that connect the nodes.

Network science relies on graph theory, which is the area of mathematics that provides the method for analyzing the relationships within a network. For example, graph theory tells us that the node degree—which is the number of links any one node has—can provide useful information. In a social network, the node degree would be how many friends one person has, which can be interpreted as how popular a person is. In a functional brain network, the 'popularity' of a brain region has implications for how important it is in processing information within that network."

"Our lab studies creative thinking: how people creatively combine concepts to form new ideas. We use network science to understand how creative thinking relates to the organization of concepts in semantic memory (our general knowledge about the word). Network science tools can be used to 'map' the relationships between concepts in memory, and to study how these maps differ in people who are more or less creative."

## Why do you think network science is useful in studying language?

"Network science can provide models for how words might be related or how words might be represented differently in different groups of individuals. It allows you to look at a number of dimensions that we know are important in language—like semantic or phonological relationships. You can also combine many of these features in one network."

"I think network science could be broadly useful in studying language because of how it can characterize complex systems—and language is definitely a complex system. For example, there is a long-standing hypothesis, that concepts within the semantic system are linked by semantic similarity and that brain activation spreads among concepts via these links. By characterizing these semantic networks, we can better understand how their structure may influence different types of behavior that rely on access to semantic knowledge, including how this structure may be affected by both developmental (such as specific language impairment) and acquired language difficulties (such as aphasia)."

"Network science gives researchers powerful tools to study how language is structured in our minds. Networks are also intuitive for people to understand, I think. And network visualizations—depicting the relationships between words in the lexicon (e.g., related words being more connected to each other, as in the graph above)—often help to facilitate that understanding."

## Could you share an interesting result from your work in network science?

"Abby Cosgrove (current fifth-year graduate student of psychology) and Amy Lebkuecher (current postdoctoral fellow at the University of Pennsylvania and Moss Rehabilitation Research Institute) have been working on several different network science projects. Abby's findings suggest that the semantic networks in older adults differ from younger adults in that they're less efficient and have more sub-groups. This is an important finding because typically, measures of older adults' comprehension show little age-related decline. For example, vocabularies are often larger among older adults compared to younger adults and older adults have very good reading comprehension. What Abby's results suggest, though, is that these increases in vocabulary affect semantic network structure and may have a cost."

"One interesting result that I have found in my research comes from a study of brain networks. I compared the networks of people with aphasia, an acquired language difficulty due to stroke or other brain injury, with those of age-matched adults without aphasia. I expected that people with aphasia would have less connected networks because of lesions that eliminated brain regions from networks. However, something I found that I did not expect was that some brain regions that were spared by the lesion and would normally be connected to a network were also disconnected. This suggests that brain regions that do not appear to be structurally affected by the lesion are functionally affected by the lesion, and that lesions have far-reaching consequences for brain networks."

“We've found that highly creative people, or those who do well on verbal creativity tests, have a unique semantic memory network: they have many connections between concepts, which might make it easier for them to connect concepts when thinking creatively. This finding has turned up across many different ways of conceptualizing verbal creativity, such as metaphor, which involves connecting concepts that are usually not related (e.g., ‘time is money’). People who can produce more creative metaphors tend to show this interconnected semantic memory network structure.”

**How do you think network science connects to our daily lives? Are there ways that people can benefit from network science projects?**

“Network science is a useful set of tools that can be used to help us understand almost anything. Advancing our understanding of how we use language can benefit people across the lifespan, as well as individuals who experience language difficulties.”

“Network science in general connects to our daily lives through things like search engines and power grids. For example, Google uses an algorithm based on the graph theoretical metric PageRank to optimize searches. My hope is that my research using network science will eventually help people with aphasia by informing treatment practices. I assume that most researchers who use network science in their research are like me and hope that it will translate into a practical benefit for society.”

“A type of semantic network that people can use in their everyday lives is called a ‘mind map’—a diagram for drawing the relationships between parts of a whole. Mind maps are often used in educational settings to visualize a student's knowledge of a concept, and to see how that knowledge map changes as students learn (e.g., about science concepts). Another way to explore your own semantic network is through free association, by saying the first word that comes to mind in response to any other word. The Small World of Words is a neat project based on free associations from thousands of research participants. Anyone can explore this semantic network to see how most people make associations to different words, just as in the example illustration above.”

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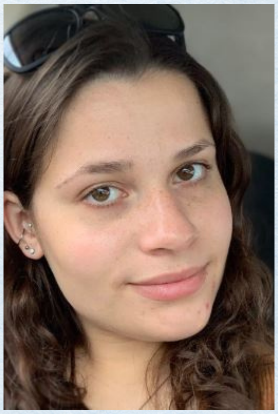

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**Bilingualism Matters** is an international organization dedicated to translating findings from research on multilingualism for general audiences.

To receive research updates, links to articles, and information about our events, check out our Facebook and Twitter pages.

The Penn State **Center for Language Science (CLS)** is an interdisciplinary research group of linguists, psycholinguists, applied linguists, speech-language pathologists, speech scientists, and cognitive neuroscientists who share an interest in language acquisition and bilingualism.

To stay up to date with CLS or to read more about new and exciting language science research, check out our Facebook and Twitter pages.

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