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Inventing and Reinventing the Cog: A Commentary on "Computational Modeling of Bilingual Language Learning: Current Models and Future Directions"

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Computational models can be considered as complete, quantified implementations of theories (Dijkstra & De Smedt, 1996). By specifying theoretical details, they allow explanations and predictions to go beyond the obvious and ordinal. The arrival of computational models in the cognitive domain of second language learning indicates that it is growing out of its infancy. This is because model implementation, clearly, can never be complete if the underlying theories are not.

What phenomena should cognitive models of second language learning account for, and how should they be progressively developed? Any good theory of language use and, hence, any computational model should cover at least four dimensions: representations in long-term memory, processes, cognitive control, and working memory. Representations can differ considerably across languages and participants (monolinguals or multilinguals, heritage speakers or native speakers, and so on). Representations can have different mutual relations within and between languages (e.g., cognates and false friends). The

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processing of representations depends on their intralingual and interlingual properties. Task requirements may induce various processing strategies that models need to take into account. Finally, working memory is paramount for second language learning. In our view, Li and Xu do not fully make these distinctions explicit.

Furthermore, models of second language learning should be built while adhering to certain developmental strategies, as recommended by Jacobs and Grainger (1994). Their strategies include, for instance, nested modeling, model-to-model comparison, and the application of precise criteria to model building and evaluation. Because second language learning is not a general or unified phenomenon, these strategies are indispensable. We stress these notions as important additions to Li and Xu's considerations.

As the authors explain, there are many different approaches to modeling. Some of them date back to the 1980s; others are currently under development. Much has changed over the decades. New information sources, including neuroscientific evidence, have become available for second language learning (van Heuven & Dijkstra, 2010). New questions have been formulated about cognitive processes in the brain (where? how?), but cognitive functionality is still a primary focus for many researchers.

We have noted a tendency in the literature (carefully avoided by Li and Xu) to consider new approaches as "better." Of course, new approaches may offer new possibilities for simulation, but they also have new limitations. For instance, deep learning is much more powerful than simple learning as in the old parallel distributed processing models (although its learning rules may be questionable from a neuroscientific perspective). However, it has the exacerbated problem of having many degrees of freedom (making cognitive models difficult to specify). Other issues are that most attention is focused on accuracy rather than response times, and that what happens takes place in a "black box" that replaces the human black box that researchers wanted to open up. Without new empirical evidence (possibly collected with innovative techniques), the new models cannot be specified any further than the older existing models. In fact, because they are older, existing models have often been specified and tested already in much more detail, depth, and breadth.

At the same time, older models have their own problems that may or may not have been resolved. For instance, interactive activation (IA) models so far have not accounted well for learning aspects. A theoretical attempt was made with BIA-d (Grainger et al., 2010), but the implementation of learning rules (as in ACT-R; Anderson et al., 2004) should be systematically explored. The modest conclusion is that at the current stage of second language learning

research, the best that can be hoped for is a model that helps in understanding the basic mechanisms underlying processing and learning. In addition, every new model represents a particular view on a limited cognitive domain and has a particular function (models are like sketches). This is in line with the multipronged approach of Li and Xu.

However, this approach will have to deal with at least two issues. First, it is problematic to replace old models with new ones or build hybrid models combining two paradigms. Li and Xu argue that their "pluralist approach" will lead to the emergence of new models that will make significant contributions to research on bilingual learning and representation. We agree that there are advantages in using new empirical data and higher level theoretical insights, but not necessarily in replacing existing models with new ones. The implementation of any model requires a considerable amount of effort, and simply dumping existing models is a waste of scientific energy. Furthermore, we note that certain approaches to hybrid modeling are simply incompatible due to inconsistent assumptions. Their comparison is fruitful, but not their integration. Our proposed modeling approach is therefore to work within one particular cognitive framework, allowing us to clarify or add pieces of the cognitive puzzle.

Second, encompassing models of second language learning cannot be built as long as the underlying mechanisms of explicit and implicit learning are unclear. There currently does not exist a detailed, valid theory of second language learning. Although models like DevLex-II are promising, there is still a lack of knowledge, for instance, about long-term learning curves or changes in the second language lexicon over time. Thus, it is not fully clear what models of second language learning should account for.

Therefore, the best top-down approach to modeling monolingual and bilingual language performance and second language learning is still to be determined. For several reasons, we argue that developing an IA-account for second language learning phenomena will be most fruitful. First of all, human researchers think and interact in terms of symbols—the basic units of IA-models. Symbolic representations are easy to use for communication and comprehension purposes. We do not deny that "reality" has a much finer-grained size, but we would argue that the IA-models do "carve nature at its joints" (Fodor, 1983, pp. 127–128). Every model is a simplification, but as long as the core mechanisms are captured (even when in reality their underlying nature is fuzzy), the model fulfills our purposes.

There are successful IA-inspired models of monolingual language processing, such as the spatial coding model (Davis, 2010) and WEAVER++ (Roelofs, 1992). Extending these models to second language learning is useful

and allows for nested modeling. A model like Multilink (Dijkstra et al., 2019) accounts for monolingual and multilingual word retrieval of different word types in different languages, participants, and tasks. In principle, learning mechanisms can be added to the model. Alternatively, because they share fundamental assumptions, we may approach second language learning by considering IA-models as the end point of parallel distributed processing models (as in BIA-d).

In sum, we agree with Li and Xu that cross-disciplinary work "is not a luxury but a necessity for success." Indeed, to reach the enduring goal of capturing the basic cognitive mechanisms underlying bilingual processing and learning, relating to different research fields is a sine qua non. Here, we have pointed out additional notions, areas, and insights to be considered. Importantly, we conclude that second language learning should be studied in interaction with monolingual and bilingual processing in general.

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