Understanding the Dynamics of Learning: The Case for Studying Interactions

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Keywords: learning; categorization; generalization; instruction; learning strategies

Motivation and Background

Most models and theories of learning envision general learning mechanisms that work similarly across most, if not all, learning contexts. However, the reality of the learning dynamics seems to be very different. Learning is not independent of the learning context, instead, the learning process is changed by the learning context. For example, different learning outcomes result from similar learning experiences with different content or learner characteristics.

Moreover, because studying the learning process is closely interconnected with studying how to improve learning outcomes, most proposals of how to improve learning follow the same context-independent principles. Although general proposals about how to improve learning outcomes have the benefit of simplicity, they have the potential drawback of failing to live up to their promise.

In this paper, I argue for the power of studying interactions between learning conditions and contextual factors. I use my research to exemplify the power of this approach not only to understand the dynamics of learning and how a learning mechanism works across multiple contexts but also to uncover robust ways to improve learning outcomes.

Interactions as a way to study learning process

Studying how the learning process is affected by different contexts can help uncover the mechanisms of learning. For example, studying the interactions between the sequence in which information is studied and what that information is, has led to a better understanding of how learning unfolds in time.

One recent focus has been on the differences between interleaved and blocked sequences. A blocked sequence is characterized by infrequent alternation between unrelated items. An interleaved sequence, on the other hand, is characterized by frequent alternation between unrelated items (Carvalho & Goldstone, 2014a).

Both sequences have been shown to boost learning. Thus, a complete understanding of the learning process and how it unfolds in time must account for the benefits of one sequence over the other in different contexts. Put another way, understanding how learning takes place in time requires understanding how different sequences interact with different contexts to influence learning outcomes.

The Sequential Attention Theory (SAT; Carvalho & Goldstone, 2015, 2017b) harnesses these interactions to explain the learning process. SAT proposes that learning in time is, at least in part, a process of sequential comparison between the information available now and information available in the immediately preceding experience. Through this process, our cognitive systems prioritize which features to encode at a local temporal level, by taking into account the potential information value of each feature compared to the corresponding feature of the previous item. This proposal is consistent with both behavioral (Jones & Sieck, 2003) and brain imaging data (Schlichting & Preston, 2015; Zeithamova, Schlichting, & Preston, 2012).

Importantly, the process described by SAT results in different information being encoded when learning unfolds in different ways. Blocked and interleaved sequences change which type of transition is more frequent. Blocked study includes a larger number of transitions between related items, whereas interleaved study includes a larger number of transitions between unrelated items. In this way, over time different properties will be highlighted and stored in memory, changing the aggregated information in potentially significant ways. In brief, blocked study encourages encoding local similarities among related items; whereas interleaved study encourages encoding local differences between unrelated items.

SAT and the novel understanding of learning and its temporal dynamics would not be possible without studying interactions between different learning sequences and context. For example, interleaved sequences improve learning of high similarity categories – when finding differences between categories is harder. Conversely, blocked sequences improve learning of low similarity categories – when finding similarities among items of the same category is harder (Carvalho & Goldstone, 2014b, 2014a).

Similarly, we showed that when learners engaged in learning activities that emphasize discrimination such as being asked to guess the category before getting feedback, they learned better if an interleaved sequence was used (Carvalho & Goldstone 2015). Conversely, when learners were engaged in a task that emphasizes finding similarities, they learned better when a blocked sequence was used instead. This pattern of results was similar for both high and low similarity categories but was reversed when using categories with more sparse structures (Kost, Carvalho, & Goldstone, 2015), which might also influence whether discrimination or assimilation processes are more relevant.

A further set of interaction-based studies more directly demonstrated that learners attend to, encode, and remember similarities across sequential items better in blocked sequences, but differences between successive items in interleaved sequences (Carvalho & Goldstone, 2017b; see also Carvalho & Albuquerque, 2012). Finally, a model in which attention and encoding are updated from trial to trial results in local encoding of sequential similarities and differences, but also category-level relevant differences and similarities, can account for most of the interactions described (Carvalho & Goldstone, 2018).

Ways to improve learning outcomes

In the previous section I highlighted how the study of context-dependencies in the learning process through studying interactions can improve understanding of the learning process and how it unfolds in time. Investigating context-dependencies also helps uncover robust ways to improve learning outcomes, namely in educational contexts. If what we learn depends on the interaction of how learning takes place and what is being learned, best learning practices should specify these dependencies.

For example, a common assumption is that the same learning mechanisms underlie both supervised and unsupervised learning. Thus, if one sequence results in improved learning outcomes in supervised learning contexts the same is expected in unsupervised learning contexts. In one classroom study, Carvalho et al. (2016) found that students who decided to repeatedly study the same topic showed higher gains in subsequent tests than students who decided to alternate topics. Importantly, this difference is tightly connected to the students' decisions, because when another group of students was presented yoked sequences no difference was found.

Similarly, the best sequence of study depends not only on what is being learned but also on how it is being tested. When the test requires knowing the similarities among items of the same category, blocked study results in improved learning (Carvalho & Goldstone, 2017a). As a final example, the benefits for transfer to new items of simultaneously studying several items of the same category depend on the type of category being studied and the type of test used (Meagher, Carvalho, Goldstone, & Nosofsky, 2017).

In sum, learning is sensitive to content and different learning is achieved with similar practices in different contexts. Thus, when making suggestions for practice, it is important – even critical – to understand and describe these boundary conditions. As described above, a good learning strategy is not good across all contexts.

Interactions in the wild

My recent work explores how learning in educational contexts, both in person and online, is influenced by context (Carvalho, McLaughlin, & Koedinger, 2017). What contextual changes influence learning from different practices in real-world settings? This type of research has the potential to contribute to a better understanding of learning in its natural environment, and to better evidence-based practices that take context-dependencies into account.

Relevant Publications

My publications most relevant to this presentation are: Carvalho and Goldstone (2014a; 2014b; 2015a; 2015b; 2017b), Carvalho et al. (2016; 2017), Carvalho and Albuquerque (2012), Meagher et al. (2017).

References

Carvalho, P. F., & Albuquerque, P. B. (2012). Memory encoding of stimulus features in human perceptual learning. *Journal of Cognitive Psychology*, *24*(6), 654–664.

Carvalho, P. F., Braithwaite, D. W., de Leeuw, J. R., Motz, B. A., & Goldstone, R. L. (2016). An In Vivo Study of Self-Regulated Study Sequencing in Introductory Psychology Courses. *PLOS ONE*, *11*(3), e0152115–e0152115.

Carvalho, P. F., & Goldstone, R. L. (2014a). Effects of interleaved and blocked study on delayed test of category learning generalization. *Frontiers in Psychology*, *5*(AUG).

Carvalho, P. F., & Goldstone, R. L. (2014b). Putting category learning in order: Category structure and temporal arrangement affect the benefit of interleaved over blocked study. *Memory & Cognition*, *42*(3), 481–495.

Carvalho, P. F., & Goldstone, R. L. (2015). The benefits of interleaved and blocked study: Different tasks benefit from different schedules of study. *Psychonomic Bulletin & Review*, *22*(1), 281–288.

Carvalho, P. F., & Goldstone, R. L. (2017a). The most efficient sequence of study depends on the type of test. In G. Gunzelmann, A. Howes, T. Tenbrink, & E. Davelaar (Eds.) *Proceedings of the 39th Annual Conference of the Cognitive Science Society* (pp. 198–203).

Carvalho, P. F., & Goldstone, R. L. (2017b). The sequence of study changes what information is attended to, encoded, and remembered during category learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *43*(11), 1699–1719.

Carvalho, P. F., & Goldstone, R. L. (2018). A computational model of sequential category learning. Manuscript in preparation.

Carvalho, P. F., McLaughlin, E. A., & Koedinger, K. R. (2017). Is there an explicit learning bias? Students beliefs, behaviors and learning outcomes. In G. Gunzelmann, A. Howes, T. Tenbrink, & E. Davelaar (Eds.), P*roceedings of the 39th Annual Conference of the Cognitive Science Society* (pp. 204–209).

Jones, M., & Sieck, W. R. (2003). Learning myopia: an adaptive recency effect in category learning. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *29*(4), 626–640.

Kost, A. S., Carvalho, P. F., & Goldstone, R. L. (2015). Can You Repeat That? The Effect of Item Repetition on Interleaved and Blocked Study. In D. C. Noelle, R. Dale, A. S. Warlaumont, J. Yoshimi, T. Matlock, C. D. Jennings, & P. P. Maglio (Eds.), *Proceedings of the 37th Annual Meeting of the Cognitive Science Society* (pp. 1189–1194).

Meagher, B. J., Carvalho, P. F., Goldstone, R. L., & Nosofsky, R. M. (2017). Organized simultaneous displays facilitate learning of complex natural science categories. *Psychonomic Bulletin & Review*.

Schlichting, M. L., & Preston, A. R. (2015). Memory integration: neural mechanisms and implications for behavior. *Current Opinion in Behavioral Sciences*, *1*, 1–8.

Zeithamova, D., Schlichting, M. L., & Preston, A. R. (2012). The hippocampus and inferential reasoning: building memories to navigate future decisions. *Frontiers in Human Neuroscience*, *6*, 1–14.