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Introducing Desirable Difficulties

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Students' performance during instruction is commonly viewed as a measure of learning and a basis for evaluating and selecting instructional practices. Laboratory findings question that view: Conditions of practice that appear optimal during instruction can fail to support long-term retention and transfer of knowledge and, remarkably, conditions that introduce difficulties for the learner — and appear to slow the rate of the learning — can enhance long-term retention and transfer. Such "desirable difficulties" (Bjork, 1994) include: spacing rather than massing study sessions; interleaving rather than blocking practice on separate topics; varying how to-be-learned material is presented; reducing feedback; and using tests as learning events.

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Our project, funded by the Institute of Educational Sciences (IES), focuses on whether the benefits of desirable difficulties generalize to realistic educational materials and contexts. In a coordinated series of laboratory and classroom experiments involving college and middle-school students, respectively, we have examined whether introducing desirable difficulties can improve the effectiveness of Web-based Inquiry Science Environment (WISE, http://wise.berkeley.edu) projects. WISE modules, on science topics such as astronomy, genetic inheritance, and chemical reactions, are customizable and are used extensively by middle- and high-school teachers around the world. Among the advantages of WISE as a research tool is that we can study variations in instruction delivered in the same classroom and also quickly propagate promising practices to new modules.

Laboratory versus Classroom

Bridging laboratory and classroom settings — the goal of IES's Cognition and Student Learning (CASL) program — requires attention to factors such as classroom management and social expectations that can be controlled in laboratory studies but influence outcomes of classroom studies. Laboratory and classroom investigations also tend to differ in other ways. For example, laboratory research on learning tends to employ simple materials, short retention intervals, and controlled conditions in an effort to distinguish between completing theories, while research on classroom instruction and lifelong learning tends to employ complex curriculum materials and assessments of retention, understanding, and transfer across intervals extending to months or years. Our research bridges these contexts by studying learning from WISE modules in both the laboratory and the classroom.

Conceptual Background

As noted above, certain conditions that pose difficulties and challenges can both impede performance and enhance long-term retention; this emphasizes an important distinction that learning theorists (e.g., Hull, 1943; Estes, 1955) found essential decades ago: namely, the distinction between the momentary activation of a memory representation, which can be heavily influenced by local conditions such as contextual cues, versus its "habit" or "storage" strength, which *is* an index of learning and reflects how interassociated or integrated that representation is with related representations in memory (Bjork & Bjork, 1992). From that perspective, two interrelated ideas from educational research are relevant and important: *inquiry instruction* and *knowledge integration* (see Linn, in press). Inquiry processes confront students with variability, require generation, interleave topics, and tap into other desirable difficulties. Achieving knowledge integration is akin to developing the kind of elaborated and inter-linked memory representation that laboratory researchers have shown will sustain access to knowledge, retard forgetting, and enhance transfer.

Nature of Our Findings

Our laboratory and classroom results are remarkably consistent with each other, but point to complexities and interactions not revealed by prior laboratory research on desirable difficulties. For example, the narrative/cumulative structure of science-learning materials results in manipulations such as interleaving and spacing having a mixture of positive and negative effects: Such manipulations can enhance retention, but sometimes impede the induction of principles and generalizations.

A more specific example is our discovery that the level and complexity of generation processes can impact learning in important ways (Richland, Bjork, Finley, and Linn, 2005). In a WISE module on the habitability of planets, generation prompts that require free-response answers are more effective in fostering long-term retention than are fill-in-the-blank prompts. In addition, free-response prompts that require integrating pieces of information on the role of planet mass *and* distance from a sun (across-topic integration) lower performance during learning relative to prompts requiring integration of pieces of information about planet mass *or* distance (single-topic integration). Consistent with earlier research, however, across-topic integration prompts led to higher performance on new questions administered after 48 hours.

These results, and others, are consistent with the importance of knowledge integration in science learning. They also suggest that the desirable-difficulties perspective and findings can be an important source of design principles towards the goal of optimizing computer-based and/or classroom science instruction.

References

- Bjork, R.A. (1994). Memory and metamemory considerations in the training of human beings. In J. Metcalfe and A. Shimamura (Eds.) *Metacognition: Knowing about knowing.* (pp.185-205). Cambridge, MA: MIT Press.
- Bjork, R. A. & Bjork, E. L. (1992). A new theory of disuse and an old theory of stimulus fluctuation. In A. Healy, S. Kosslyn, & R. Shiffrin (Eds.), *From learning processes to cognitive processes: Essays in honor of William K. Estes* (Vol. 2, pp. 35-67). Hillsdale, NJ: Erlbaum.
- Estes, W. K. (1955). Statistical theory of spontaneous recovery and regression. *Psychological Review, 62*, 145-154.
- Hull, C. L. (1943). *The principles of behavior.* New York: Appelton-Century-Crofts.
- Linn, M. C. (in press). The Knowledge Integration Perspective on Learning and Instruction. In Sawyer, R. Keith (Ed.) *Cambridge Handbook for the Learning Sciences.* Cambridge, MA: Cambridge University Press.
- Richland, L.E., Bjork, R.A., Finley, J.R., & Linn, M.C. (2005). Linking cognitive science to education: generation and interleaving effects. In B. G. Bara, L. Barsalou and M. Bucciarelli (Eds.) *Proceedings of the Twenty-Seventh Annual Conference of the Cognitive Science Society.* Mahwah, NJ: Lawrence Erlbaum.

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