

Acquisition of Cognitive Skill: Do We Already Have a Theory?

Stellan Ohlsson (stellan@uic.edu)

Department of Psychology, University of Illinois at Chicago
1007 West Harrison Street
Chicago, IL 60607 USA

Keywords: cognitive skill, skill acquisition, unified theory.

Background The acquisition of cognitive skill is studied in artificial intelligence, cognitive anthropology, cognitive psychology, robotics and other cognitive sciences. Researchers have produced multiple, apparently competing theories. I argue that the seemingly diverse theoretical proposals are in fact components of a unified theory and that the latter is already in a technical sense complete.

Framework for a Unified Theory Improvements in a skill cannot come out of thin air. A learning mechanism takes information of some sort as input. For example, generalization might take a rule but also some positive examples as input and produce a more general version of that rule (*Information Dependence*).

Information that might be available in a skill learning scenario comes in different types, and each type requires a different learning mechanism. To learn from positive examples requires a different mechanism than to learn from errors, which in turn requires a different process than learning from direct instruction (*Information Specificity*).

It is plausible that people evolved to be maximally effective learners, i.e., we can make use of every type of information (*Maximally Effective Learning*). A unified theory of skill acquisition should therefore include (at least) one learning mechanism for each information type.

Core of the Theory The types of information available to a learner during practice include the following nine: (a) Direct instructions. (b) Declarative knowledge. (c) Weak methods. (d) Demonstrations/solved examples. (e) Solutions to analogous problems. (f) Positive outcomes. (g) Negative outcomes. (h) Internal execution traces. (i) Statistical regularities in the environment. I claim that this is the complete list of relevant information types. But cognitive scientists have already specified learning mechanisms for all nine information types. In conjunction, those mechanisms constitute a complete and unified theory.

Discussion There are three implications: First, it is useless to test psychological models of single mechanisms against data. Second, adaptive A.I. systems should be equipped to learn from each type of information. Third, intelligent tutoring systems are maximally effective when they support all nine modes of learning.

Acknowledgments

Preparation of this paper was supported by Award N000140910125 from the Office of Naval Research (ONR), US Navy. I thank P. Langley and K. VanLehn for inspiring discussions.

References

- Mitrovic, A., & Ohlsson, S. (1999). Evaluation of a constraint-based tutor for a data-base language. *International Journal of Artificial Intelligence and Education*, 10, 238-256.
- Nokes, T., & Ohlsson, S. (2005). Comparing multiple paths to mastery: What is learned? *Cognitive Science*, 29, 769-796.
- Ohlsson, S. (1993). The interaction between knowledge and practice in the acquisition of cognitive skills. In A. Meyrowitz and S. Chipman, (Eds.), *Foundations of knowledge acquisition: Cognitive models of complex learning*. Norwell, MA: Kluwer Academic Publishers.
- Ohlsson, S. (1996). Learning from performance errors. *Psychological Review*, 103, 241-262.
- Ohlsson, S. (2008). Computational models of skill acquisition. In R. Sun (Ed.), *The Cambridge handbook of computational psychology*. Cambridge, UK: Cambridge University Press.
- Ohlsson, S. & Halpern, A. (1998). Strength adjustment in hierarchical learning. In M. A. Gernsbacher and S. J. Derry, (Eds.), *Proceedings of the Twentieth Annual Conference of the Cognitive Science Society*. Mahwah, NJ: Lawrence Erlbaum.
- Ohlsson, S. & Mitrovic, A. (2006). Constraint-based knowledge representation for individualized instruction. *Computer Science and Information Systems*, 3, 1-22.
- Ohlsson, S., & Rees, E. (1991a). The function of conceptual understanding in the learning of arithmetic procedures. *Cognition & Instruction*, 8, 103-179.
- Ohlsson, S., & Rees, E. (1991b). Adaptive search through constraint violations. *Journal of Experimental and Theoretical Artificial Intelligence*, 3, 33-42.
- Ohlsson, S., & Regan, S., (2001). A function for abstract ideas in conceptual learning and discovery. *Cognitive Science Quarterly*, 1, 243-27.
- Youmans, R., & Ohlsson, S. (2008). How practice produces suboptimal heuristics that render backup instruments ineffective. *Ergonomics*, 51, 441-475.