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Toward an Operational Definition of the Zone of Proximal Development for Adaptive Instructional Software

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Introduction

Measuring and comparing student learning in adaptive computer assisted learning (ACAL) systems is problematic because the system is trying to both model *and* change the user, and in this sense is chasing a moving target. Process-oriented metrics for measuring learning, such as the zone of proximal development (ZPD) can be more robust in such situations. Though the concept of the ZPD is often invoked in the context of instructional systems, it has not been operationalized in a manner that allows it to be used in ACAL. We propose a straight-forward method for measuring ZPD-learning that focuses on the ongoing amount of hints or help that learners need as they solve problems. The ZPD is commonly used to articulate apprenticeship learning approaches, scaffolding and fading (note: references removed from this extended abstract, available from the authors), and authentic (situated) learning tasks. The ZPD describes a zone within which tasks are too difficult to accomplish without assistance, but which can be accomplished with some help. The ZPD in terms of a student's "readiness" to learn a new skill in terms of the assessment of learning potential or "learnability". These descriptions of the ZPD are useful for framing certain educational issues, but they are not defined in an operational way. We argue that keeping the learner within this optimal zone could be described in several compatible ways:

- Putting a greater emphasis on monitoring learning *processes* variables and maintaining *efficient* as well as effective learning;
- *Cognitively* there is a goal to presenting material that is neither too easy nor too difficult;
- *Affectively* there is a goal of avoiding the extremes of boredom and confusion (being overwhelmed);
- This can also be seen as maintaining a constant level of *challenge* (and support), or a constant "rate" of learning.

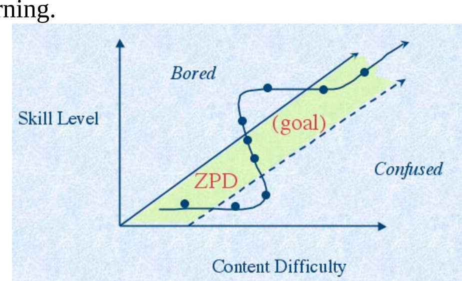

Figure 1: ZPD Illustration

Figure 1 illustrates our interpretation of the ZPD. It shows a "state space" diagram illustrating a student's trajectory through time in the space of tutorial content difficulty versus the student's evolving skill level. The goal is to give content that match the student's evolving skill level by providing just the right amount of challenge.

An operational definition of the ZPD

We define a problem equivalency set (PES) as the set of all of the problems that address the same topic(s) at approximately the same level of difficulty. We define the "specific ZPD" (SZPD) to have three parameters that could be set in an ACAL: H, the goal number of hints in a PES; P the minimum number of problems in a PES; and dH, the acceptable variation in H. Thus the goal is to keep the number of hints in a PES between H+dH and H-dH (while guaranteeing that the student sees at least P problems). The scheme has the following properties, it is: non-monotonic (allows for learner forgetting and unsystematic error in student model); forgiving (recent behavior has more weight); accommodates to different learning styles (e.g. gradual vs. normative vs. insightful learning); tolerant to slips & guesses (one behavior can't make a big difference). The SZPD parameters H, P, and dH in each tutoring system (or content module) are adjusted by a content expert to account for task difficulty calibration, and the teacher's pedagogical style.

We are using this method for two purposes in evaluating/diagnosing student learning: *dynamic* evaluation that enables adaptive instruction, and *formative* evaluation that inform future ACAL design. In our post-hoc analysis of data from Animalwatch arithmetic and fractions tutor (three studies over three years on a total of 350 subjects) we have used our ZPD approach to monitor "hint flow" in the analysis of the pedagogical model, the student model, and the content model of the tutor. To evaluate the pedagogical model we analyzed trends in student model proficiency levels vs. problem difficulty, to evaluate content accuracy we analyzed assigned difficulty of a problem vs. average number of mistakes students made on the problem; to evaluate student model accuracy we compare trends in problem time, average mistakes, and student mastery over the Nth problem seen. We also look at trends in hints vs. problem solving time to assess whether students are authentically engaged in problem solving. Preliminary data, graphs, and analysis is available in other papers by the authors, and the analysis is still in progress.