

Facilitating Collaborative Problem Solving with *Distant Mentor*

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INTRODUCTION

This work addresses the problem of helping learners develop concepts and skills needed to be productive in the fast-changing technical workplace. It marries the kind of informal, on-demand learning preferred by workplace professionals and advocated by learning theorists with the support for learning at a distance afforded by networked computing environments (Schlager, Means, O'Day, & Poirier, 1994). Our *cognitive mentoring* model of collaborative learning (Schlager, Poirier, & Means, 1996) is based on the idea of individually tailored assistance provided at the learner's request when an impasse is encountered in problem solving. We have studied such interactions in the workplace (as well as classroom interactions) and developed a synchronous collaboration/simulation environment called *Distant Mentor* (DM) to facilitate mentoring from a distance (Schlager et al., 1994). This report describes a study that demonstrates how our prototype technology can support cognitive mentoring over a computer network.

Cognitive Mentoring Concepts

We define cognitive mentoring as joint problem solving involving a more knowledgeable colleague (mentor) and a less knowledgeable peer (learner) in the context of actual work and work-related tools (rather than in an isolated training environment inhabited by instructional tools). In contrast to tutoring, the mentor doesn't necessarily know the learner's problem or the right answer, but rather uses domain expertise to work jointly with the learner to overcome the impasse. We have identified several mentoring stages, including problem definition, diagnosis, execution of actions, solution evaluation, and reflection. In practice, movement through these "stages" is not strictly sequential but rather highly recursive. Within each stage, we have identified a number of specific processes (e.g., demonstration, scaffolding) that learners and mentors execute. See Schlager, Poirier, and Means (1996) for a more detailed description of mentor and learner behaviors in cognitive mentoring.

Distant Mentor Prototype

DM allows people in different locations working in a networked UNIX environment to jointly interact with a circuit board manufacturing simulation while maintaining a conversation over a network-based audio channel. DM supports both natural-language database querying and point-and-click gestures to rewind and step through the simulation for information needed to diagnose the cause of manufacturing problems, and provides a history of prior queries and answers for easy review (see Schlager et al., 1994).

Issues Addressed by the Study

Using the system, we examined questions such as: How does the aid of a mentor improve the speed and quality of subjects' solutions, and at what cost? (e.g., Does the investment of the mentor's time result in an overall person-time savings or loss?) Does our laboratory study evoke the kind of dialogue and collaborations that we observe in real workplace training sessions (Schlager et al., 1994)? How much do mentoring styles vary, and is one style more effective than another? Does DM afford

any advantages over a mode of distant collaboration that is used commonly today—the telephone and fax machine? (We did not compare DM with face-to-face mentoring because we were interested in the quality of assistance possible when people are *not* co-located.) Do mentors and learners using DM gain a shared sense of the problem more quickly (e.g., the learner needs to provide fewer verbal explanations to describe the problem history and context), and is this reflected by less time spent in the definition stage?

METHOD

Twelve San Jose State University (California) undergraduates in industrial engineering were recruited as subjects/learners (six women and six men), and two graduate students (one man and one woman) with related teaching and work experience were recruited as mentors. Before the study, all subjects and mentors received training in all conditions (see below), and mentors successfully solved practice problems with at least two pilot subjects.

Subjects worked alone or with one of the two mentors to solve two problems. Three conditions were employed, all balanced for gender: (1) *Solo*: Subjects used the system to solve problems independently, without the aid of a mentor. (2) *DM*: Subjects solved problems with the help of a mentor, using the full, joint interactive capability of the system. (3) *Fax*: Subjects had access to the mentor via an audio channel but could send only *snapshots* of the current DM screen to the mentor as needed. Four subjects solved the first problem in the DM condition and the second in the Fax condition, and four others worked in the Fax condition first and DM second. Four control subjects solved both of their problems in the Solo condition. Each condition was thus represented by eight problems.

Problems

The simulated shop floor and the production problems were designed in cooperation with a professor of industrial engineering at San Jose State University. Our goal was to make the problems authentic and complex enough to challenge even the mentors. In each problem, a simulation had been run with one or more parameters changed from the "normal" run, on which all machines were working properly and all boards had the same priority. Hence, the boards finished in a different order than expected. For example, one problem read: *A number of boards are extremely late in finishing relative to their normal finishing times. Find them and diagnose the root cause.* Complete problem solutions contained two to four subparts, and the parameters were varied to ensure that the mentors did not know the problem solution in advance.

Procedure

The mentor sat in a separate room, isolated from the learner except through the network. Mentors brought their own real work to the sessions to work on when not involved in mentoring. Mentors were not given any specific instructions as to pedagogy; they were told to respond as they would if asked

for help by a colleague in the workplace (i.e., take a problem-centered orientation rather than a tutorial one). Subjects were instructed to contact the mentor for help as needed. When the mentor and the learner felt they had the solution, they would consult the experimenter. If the solution was correct and complete, the subject was instructed to go on to the next problem; otherwise, the experimenter would inform the mentor and ask them to continue. When the pair felt they had the solution a second time, the experimenter would ask them to move on whether or not the solution was complete, to avoid frustrating the subjects. At the end, subjects completed a debriefing questionnaire.

Data Capture and Analyses

Sessions were videotaped, transcribed, and coded into cognitive mentoring stages. ANOVAs and paired comparisons were conducted to assess the effects of condition on several measures, including solution time, mentoring time and stages, and solution completeness. See Schlager, Means, and Schank (1996) for a more detailed discussion of these (and additional) analyses and observations.

SUMMARY OF RESULTS

Solution Times and Completeness

Mean solution time was 83 minutes for Solo subjects; mentored subjects solved the problems significantly faster (36 and 40 minutes for subjects in DM and Fax sessions, respectively; $p < .05$). Subjects in DM sessions solved all problems completely. Only half of the Fax subjects came to a complete solution, and the rest (each) solved only 50% of the problem, resulting in a significantly lower mean completeness of 75% ($p < .05$). Mean completeness for Solo subjects was 86% (which did not differ significantly from the other groups). In a post-hoc test of overall problem-solving productivity, we summed the mentoring and total solution times (i.e., the number of "person minutes" spent on the problem), and found a significant savings (34%) for the DM participants (only) over the Solo group ($p < .05$).

Mentoring Stages and Interactions

Overall, problem diagnosis represented the largest percentage of mentor-learner interactions (44%), followed by execution (26%), definition (15%), reflection (13%), and evaluation (2%). Transitions between stages closely resembled findings from workplace training sessions (Schlager et al., 1994), mainly alternating between diagnosis and execution or reflection. Percentage of time spent in each stage did not vary significantly by condition. However, the trend was for subjects in DM sessions to spend more time in reflection and less in definition. Also, mentors in the Fax sessions appeared to exert more overhead effort trying to keep up on the current problem state (e.g., they made significantly more requests for information on recent findings, and subjects in Fax sessions had to "take the lead" in suggesting what to do next more often than subjects in DM sessions did; $p < .05$).

Mentoring Styles and Subjective Evaluations

Qualitative results suggest that one mentor tended to use a more collaborative style, assuming joint responsibility in problem solving, whereas the other tended to use a more consultative style, offering more general advice versus hands-on engagement. Quantitative results support these observations, in that the consultative mentor held more (and shorter) conferences, spent more time in the definition stage (coming up to speed on the

state of the problem), suggested fewer actions, and provided less scaffolding ($p < .05$ for all) compared with the more collaborative mentor, who had a more active, hands-on style. Stylistic differences did not significantly affect solution time or quality, however, and subjects' satisfaction did not vary significantly by mentor. Finally, all but one subject felt that DM was as effective as face-to-face coaching, and three felt it was actually more effective than face-to-face coaching.

DISCUSSION

The flow of interactions was similar to those observed in workplace training sessions, suggesting that the tasks approximated real-world complexity. We expected subjects in DM sessions to spend significantly less time in the definition stage than Fax subjects, but mentoring stage times and flow did not significantly differ by condition. Still, the pattern of learner performance suggests that DM affords significant advantages over both individual and collaborative telephone/fax problem solving. Although the connection to a mentor alone is helpful (as demonstrated by the reduced time for mentored versus solo problem solving), Distant Mentor technology goes beyond this connection to provide an environment where learner and mentor can refer to objects and actions readily and through multiple media (e.g., by pointing with the cursor as a substitute for, or a supplement to, verbal descriptions of the referent). This capability seems to reduce misunderstandings and cognitive load and increase the proportion of time that the mentor and the learner are mentally "in synch," resulting in higher-quality solutions and an overall time savings that more than offsets the investment of the mentor's time.

Variability in mentoring styles was apparent. Although both styles had advantages and disadvantages, stylistic differences appeared to "wash out" in that they did not significantly affect solution time or quality. An important caveat is that we worked with subjects over a limited time (about 4 hours), and we did not examine the impact of mentoring style on subjects' learning and ability to solve problems over time.

Although much remains to be done, our research suggests that network-based cognitive mentoring has potential for improving the productivity and quality of distributed teamwork. Our future work will explore field implementation issues and the design and assessment of other multi-user collaborative environments.

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