Adaptive Teaching Strategies to Improve Individual Student Achievement in Problem-Based Learning Environments

Rebecca Denning
Center for Cognitive Science
The Ohio State University
USA
rdenning@magnus.acs.ohio-state.edu

Philip J. Smith
Cognitive Systems Engineering Laboratory
The Ohio State University
USA
psmith@magnus.acs.ohio-state.edu

Abstract: This study investigates the use of adaptive teaching strategies to promote learning in cooperative learning settings. The Biology Sleuth, a problem-based learning environment, was developed as a testbed to vary the distribution of critical resources and to examine the use of teaching strategies and their effects on group dynamics and individual learning. Students work in small groups, aided by various resources including a knowledge-base, each other, the software, and the teacher. This study examines the effects of applying two different teaching strategies and suggests that these strategies can have a large impact on both group dynamics and individual learning. A 35% improvement ($p < .05$) was measured in the treatment group. Based on this work we suggest that while many design features are chosen while developing training tools, designers also need to explicitly consider how these environments can be adapted during use to maximize the learning experience.

Introduction

The Biology Sleuth is an interactive learning environment designed to teach important problem-solving skills, specifically, diagnostic reasoning [Albanese & Jacobs 1990; Carlson & Delany 1988; Charniak & McDermott 1985; Cicourel 1987; Clancy 1985; Elstein, et al. 1978; Mittal, Chandrasekaran & Smith, 1979; Peng & Reggia 1990; Pople 1982; Reggia, et al. 1985], to high school students. Secondary goals of The Biology Sleuth include improving students' knowledge of health science and biology, computer literacy, social and communication skills, and increasing students' awareness of possible health science careers.

This cooperative learning environment has been developed so that students work in groups [Cohen 1994; Cousins & Ross 1993; Thousand 1994; Cook 1991; Cooper & Meuck 1990; Duffy & Knuth 1989], aided by both the software, each other, and the classroom teacher. Specifically, the students play the role of physicians. They work together in groups of three students each group assigned to a single computer. The students are presented with nine problem-solving episodes in the form of hypothetical patients. Initially they are asked to identify the hypotheses which could explain the pattern of clinical results associated with each patient. As these skills become more practiced, they are also asked to begin running tests and interpreting data for themselves. Finally, they are asked to choose individual tests which are the most diagnostic for a particular instance.

If students need assistance, they may request help from other students or the classroom teacher. The teacher is also made aware of whether a group is having difficulty by audible feedback supplied by the computer system whenever it detects an error. Similarly, the software provides additional feedback to the students to help them remediate their own errors.

The Biology Sleuth has been evaluated at 20 schools, including rural, suburban, and inner city schools in five different geographical regions of the U.S.. Over 2000 students have participated in these evaluations. A final summative evaluation using a pre-test/post-test score comparison (using a between-subjects design) indicated that The Biology Sleuth is a very powerful tool, especially for populations at risk of academic failure and for groups typically underrepresented as professionals in science [Denning & Smith 1995].

The goal of this particular study, however, was to use this context to explore the effects of different teaching strategies and resource allocations on group dynamics [Douglas 1983] and, subsequently, on individual learning, and to help develop guidelines for using such an educational tool. This study suggests that focusing on resource allocation and the teaching strategy employed can significantly influence group problem-solving behavior and individual learning in this type of environment.

Methods

Becker [1993] suggests that, while cooperative learning has become one of the most popular instructional reforms in the U.S. in the past five years, not all forms of cooperative learning work as well as some might believe. He reports that research evidence strongly suggests that peer interaction alone is not sufficient to help students learn. Rather, cooperative teams should be structured such that while the group may be rewarded for good performance, all group members retain responsibility for their own achievement and productivity.

The social psychology literature [Douglas 1983] indicates that constraints such as access to information, distribution of resources, knowledge, or input to a computer system, can be manipulated in order to influence such group and individual behaviors. This general finding was used to guide part of the design of The Biology Sleuth.

In particular, one design goal was to influence students to develop explanations for successful and unsuccessful problem-solving. (The literature (Chi et al. 1989) indicates that learning is more likely to occur on problem-solving tasks if the student develops such explanations.) To accomplish this goal the students worked using The Biology Sleuth in groups of three; each group had access to the data and symptom information through a shared medium (ie., a single computer), thus encouraging interactions among group members; each group was allowed to enter a single conclusion for each patient case, thus inducing group discussion in order to arrive at a consensus; the "knowledge-base" relating test results to particular diseases was distributed to each student individually [as a paper chart], encouraging the students to do their preliminary problem-solving individually.

It was hypothesized that such a design, providing for distribution of a key resource (the knowledge-base), would help students to detect errors (when the students in a group found that their individually derived answers disagreed) and to develop explanations in order to resolve these disagreements and arrive at a group consensus. In particular, providing the chart of clinical results associated with the diseases in paper form and providing each student with his or her own copy of this paper form was expected to encourage each student to actively engage in the problem-solving task on his own, forming his own hypotheses, comparing them with the hypotheses generated by his peers, and developing explanations to account for any disagreement.

Given Becker's research, The Biology Sleuth was designed to provide the following structure to the groups. First, the group is rewarded through positive, audible feedback when they reach the correct answer to a problem. Second, individual group members are responsible for their own performance in two ways. The distribution of knowledge (on the paper forms) to each student is intended to encourage each student to provide input to the group after he works individually to generate a hypothesis. In addition, the students are also told, prior to using the system, that they are preparing to take an individually answered test and that the experience with the system is provided to help them "study" for that test. Finally, cooperation between students is stressed during the learning process. Since the principal reward, audible feedback, is provided to the group, behaviors such as individual students helping each other, and detecting and correcting the problems and misconceptions of the other students in their group, are encouraged. The act of generating an explanation for another group member should not only help to remediate that individual's knowledge, it should also help the student who is generating that explanation to think more deeply about the situation in question.

In the original design of this system, each student in a group of three was given his or her own copy of the knowledge-base. By distributing the chart in this manner, it was hoped that all the students would generate their own hypotheses. Since the computer would only accept a single answer for each case, they would then have to come to some agreement about the group's answer in the event that their individually generated hypotheses did not match. It was hoped that in such situations students would discuss their problem-solving methods in the process of reaching a consensus and thus teach each other. Videos made during the initial formative evaluations of The Biology Sleuth revealed that many groups behaved as intended. First, as a group, they first select a particular datum from the computer display for consideration. Second, individually they look at their paper charts (the "knowledge-base") to find the hypotheses consistent with that datum. Third, as a group they compare the intermediate hypotheses generated in this fashion, providing explanations to each other when there was disagreement or confusion. Fourth, they continue this process until the case is solved.

The distribution of resources (in this case, the "knowledge-base") to all of the individuals was quite successful for most students. As we started to study "at risk" populations, however, there were groups where one student lagged behind the others and "followed along" as the others did the problem-solving exercises. Unable to keep up with the rest of the group this member was often ignored by the other students who were busily engaged in the problem-solving exercises. Intervention by the teacher, suggesting that the more advanced students help explain the methods to the slower student, occasionally resulted in peer tutoring. More often, though, the advanced students seemed uncomfortable with the role of teaching and ignored the teacher's suggestion.

As an experiment, to encourage the students to participate more fully, the resources critical to the problem-solving task were redistributed to induce the advanced students to take on the role of teacher for the students who were experiencing problems. Further, the role of the slower students was also changed, and they were given a central role in producing an answer for the group. Resources were redistributed in the following way: Step 1: The students were rearranged physically in front of the computer with the student having difficulties placed in the middle of the group. Step 2: The knowledge-base, pens, and pencils were taken away from all students, except the student who was experiencing problems. Step 3. The student having problems was given control of the mouse and, consequently, the responsibility to enter an answer for the group. (This was done with the explanation by the teacher that everyone needed a chance to work with the mouse, so as to avoid putting a stigma on the slower student.)

Subjects

The students who participated in this evaluation attended an urban public school in a West Coast State. Of the 25 students who participated, nine were Asian-Americans, eight were Hispanic, five were Caucasian, and four were African-Americans. Eleven were male, fourteen were female. All were of low socio-economic status.

Procedure

Two equivalent classes of students were randomly assigned to either the treatment or the control groups. All students were instructed that they were using the system to prepare for a test and that they should help teach each other if a group member was having trouble with the exercises. All students in each group were given their own copy of the knowledge-base for all nine problem-solving exercises.

The groups in the treatment condition were rearranged, as described above, at the first indication that any group member was lost and unable to participate in the group's problem-solving activities.

Results

Video tapes of the students' interactions revealed that the redistribution of resources did change the roles of the students within their groups. Students who had previously excelled at the problem-solving task, and were still highly motivated to get the correct answers, now took on the job of working with the troubled group member (in effect now teaching that student, even though their explicit goal was still just to get the problem right). Further, the video indicated that the students who had previously allowed others to take the responsibility for their group's success or failure became more engaged in the problem-solving exercises, actively generating hypotheses and marking the knowledge-base for their group.

A test question was devised to help assess whether students individually learned to select the piece of data which would be the most diagnostic if trying to refine a set of hypotheses to a single hypothesis regardless of their group's interactions. This test was on the topic of archeology to assess whether students were able to generalize the problem-solving skills which were emphasized as they worked with the system. The test was given to all students in both the treatment and control conditions after working with the system. The results suggest that there were benefits both for the students who had experienced difficulties early in the problem-solving exercises and for the students who had taken on the role of teaching those students. In the control group, only 29% of the students were able to generate a set of hypotheses and then to identify the most diagnostic test to run to refine that hypotheses set. In the treatment group, however, 64% of the students were able to perform this task. The treatment group improved 35% from the control group. This improvement is statistically significant with $p < .05$ [Eberhardt and Fligner 1977; Robbins 1977].

Discussion

We can see that the treatment group, in which resources were redistributed, showed quite an improvement from the control group. By controlling the distribution of critical resources, the group dynamics [Douglas 1983] were altered drastically. By using resource allocation students new roles within that group, the students who had been successfully completing the problem-solving task by themselves directed their energy to working with a troubled student because he or she now had control of the critical resources, the knowledge-base, pen and the mouse, for solving the case and entering the group's answer. These students, who had previously experienced problems, became interested in the group's activities and individually engaged in the problem-solving processes. This new group configuration resulted in learning for both the students who were taught by their peers and the students who provided the tutoring.

Summary

Research on cooperative learning and instructional design have focused on strategies that can be employed in order to develop productive and efficient training environments [Gustafson and Tillman 1991]. This research suggests global design strategies to improve learning, such as suggestions about group sizes [Gagne, Wager and Rojas 1991]. Winn [1987] suggests that instructional design and teaching are very similar. In both cases, decisions must be made about the methods to employ in order to reach a particular training objective. He continues that the difference lies in the fact that the designer of training systems is forced to decide which method to use prior to the implementation of instruction, and that teachers can change their methods while in the process of teaching if necessary.

Given these comments and by watching what happens when various teaching strategies are applied in the classroom, it seems clear that designers should not limit themselves to designing training systems and then leaving the choice of teaching strategy to the person supervising the environment. Rather, there is a need for a theory of adaptive teaching strategies which can be suggested by the designer of a training environment to the teacher who will be teaching when the environment is in use. By designing the teaching strategies to be employed during such interactions and making those strategies readily available to the teacher the training experience can be improved.

References

Albanese, M., & Jacobs, R. [1990]. Reliability and validity of a procedure to measure diagnostic reasoning and problem-solving skills taught in predoctoral orthodontic education. Evaluation and the Health Professions, 13[4], 412-424.

Becker, H. J. [1993]. A model for improving the performance of integrated learning systems: mixed individualized/group/whole class lessons, cooperative learning, and organizing time for teacher-led remediation of small groups. In G. D. Bailey [Ed.], Computer-Based Integrated Learning Systems. Englewood Cliffs, NJ: Educational

Technology Publications.

Carlson, R., & Dulany, D. [1988]. Diagnostic reasoning with circumstantial evidence. Cognitive Psychology, 20[4], 463-492.

Charniak, E., & McDermott, D. [1985]. Introduction to artificial intelligence [Chapters 8 and 10]. Reading, MA: Addison-Wesley.

Chi, M.T.H., Bassok, M., Lewis, M.W., Reimann, P., & Glaser, R. [1989]. Self-explanations: How students study and use examples in learning to solve problems. Cognitive Science, 13, 145-182.

Cicourel, A. [1987]. Cognitive and organizational aspects of medical diagostic reasoning. Discourse Processes, 10[4], 347-367.

Clancy, W. [1985]. Acquiring, representing, and evaluating a competence model of diagnostic strategy [Report No. HPP-84-3: STAN-C5-85-1067].: Stanford University, Department of Computer Science.

Cohen, E. G. [1994]. Restructuring the classroom: Conditions for productive small groups. Review of Educational Research, 64[1], 1-35.

Cousins, J. B., & Ross, J. A. [1993]. Improving higher order thinking skills by teaching "with" the computer: A comparative study. Journal of Research on Computing in Education, 26[1], 94-115.

Denning, R., & Smith, P.J. [1995]. Design changes based on the needs of students "at risk" of academic failure [CSEL Technical Report No. 218-1995]. Columbus, OH: The Ohio State University, Cognitive Science Engineering Laboratory.

Douglas, T. [1983]. Groups understanding people gathered together. London: Tavistock Publications.

Duffy, T. M., & Knuth, R. A. [1990]. Hypermedia and instruction: Where is the match? In D. H. Johassen & H. Mandl [Eds.], Designing hypermedia for learning. Berlin: Springer-Verlag.

Eberhardt, K. R., & Fligner, M. A. [1977]. A comparison of two tests for equality of two proportions. American Statistician, 31[4], 151-155.

Elstein, A., Shulman, L., & Sprafka, S. [1978]. Medical problem solving -an analysis of clinical reasoning. Cambridge, MA: Harvard University Press.

Gagne, R. M. Wager, W., & Rojas, A. [1991]. Planning and authoring computer-assisted instruction lessons. In L. J. Briggs, K. L. Gustafson & M. H. Tillman [Eds.], Instructional design principles and applications [2nd ed.]. Englewood Cliffs, NJ: Educational Technology Publications.

Gustafson, K. L., & Tillman, M. H. [1991]. Designing the general strategies of instruction. In Briggs, L. J., Gustafson, K. L. & Tillman, M. H. [Eds.], Instructional design principles and applications [2nd ed.]. Englewood Cliffs, NJ: Educational Technology Publications.

Mittal, S., Chandrasekaran, B., & Smith, J. [1979]. Overview of MDX - a system for medical diagnosis. Proceedings of 3rd Annual Symposium on Computer Application in Medical Care, IEEE, 34-46.

Peng, Y., & Reggia, J. [1990]. Abductive inference models for diagnostic problem-solving. New York: Springer-Verlag.

Pople, H. [1982]. Heuristic methods for improving structure on Ill-structured problems: The structuring of medical diagnostics. In P. Szolovits [Ed.], Artificial intelligence in medicine [pp. 119-190].

Reggia, J., Nau, D., Wang P., & Peng, Y. [1985]. A formal model of diagnostic inference. Information Science, 37, 227-285.

Robbins, H. [1977]. A fundamental question of practical statistics. American Statiscian, 31[4], 97.

Thousand, J. S.[Ed.] et al. [1994]. Creativity and Collaborative Learning: A Practical Guide to Empowering Students and Teachers. Baltimore, MD: Paul H. Brookes Publishing.

Tonta, Y. [1992]. Indexing in hypertext databases. In S. Stone & M. Buckland [Eds.], Studies in multimedia state-of-the-art solutions in multimedia and hypertext. Medford, NJ: Learned Information.

Winn, W. [1987]. Instructional design and intelligent systems: shifts in the designer's decision-making role. Instructional Science, 16, 59-77.

Young, M. F., & Kulikowich, J. M. [1992, April]. Anchored instruction and anchored assessment: An ecological approach to measuring situated learning. Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco.