Adaptation and Understanding: A Case for New Cultures of Schooling

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Running head: ADAPTATION AND UNDERSTANDING

Abstract

We argue that efforts at school restructuring should focus on altering classroom conditions that make minimal understanding strategies adaptive. Toward this end we analyze conditions of schooling that inhibit efforts at understanding, and contrast these with conditions that encourage students to pursue understanding by their own initiative. Our analysis of conditions necessary to enable purposeful pursuit of understanding is based on our experience in developing and implementing a computer-based system (CSILE) for information sharing and knowledge advancement. Results from the use of CSILE suggest that it is possible to create school environments that give understanding a central role and that the benefits from doing so are considerable.

Adaptation and Understanding: A Case for New Cultures of Schooling

The effort to understand and explain phenomena can have considerable adaptive value, as Roger Schank (1986) has shown. When events do not conform to our expectations, trying to explain them may provide a basis for more accurate predictions in the future. It is often suggested that an urge to understand is innate in humans. This may be true, but the statement needs qualifications. In the first place, human beings are much more inclined to explain unusual phenomena than to explain usual ones. This is consistent with Schank's view that it is failed expectations rather than some general explanatory urge that lies behinds efforts at understanding, with van Lehn's account of explanation as impasse driven (van Lehn, 1990), and with Berzonsky's (1971) demonstration that students are better at explaining malfunctions than normal functions. A second qualification is essential if we are to consider understanding within an adaptationist framework: Under some conditions it is adaptive not to seek understanding. This fact takes on great importance in the context of schooling. School is a place where the pursuit of understanding is supposedly given a high priority, but it is also a social institution in which the most adaptive thing for students to do may be not to try to understand.

A great deal of cognitive instructional research may be interpreted as suggesting that students are not investing much effort in understanding what they are exposed to in school. Salient examples are research indicating (1) lack of comprehension monitoring (August, 1984; Gardner, 1980, 1987; Markman, 1979, 1981; Paris, 1981; Scardamalia & Bereiter, 1984); (2) use of the "copy-delete" strategy in summarization (Brown & Day, 1983; Brown, Day, & Jones, 1983)--

evaluating propositions one-by-one rather than identifying superordinate propositions; (3) use of the "knowledge-telling" strategy in writing, which involves telling what one knows under minimal topical and structural constraints; (4) prevalence of scientific misconceptions that are resistant to instruction (Anderson & Smith, 1984; Shayer & Wylam, 1981; Vosniadou & Brewer, 1987); (4) poor comprehension of mathematical word problems and giving of implausible answers (Davis, 1981; Holt, 1964; Schoenfeld & Herrmann, 1982); and (5) the superficiality and competitiveness observed in student discussions (Eichinger, Anderson, Palincsar, and David, 1991).

While these kinds of behavior are often regarded as maladaptive, an alternative view, persuasively argued by John Holt in How Children Fail (1964), is that such behaviors are in fact intelligent responses to school conditions in which it is adaptive not to invest effort in understanding. If this alternative is correct, educational reformers might better focus on changing school environments than on changing students' cognitive strategies. That is the view that underlies our approach to designing a computer-based environment for schools--CSILE (computer-supported intentional learning environments).

In this essay we examine a number of ways in which school conditions may make it adaptive not to seek understanding. Then we discuss school conditions that should shift the adaptive bias back in favor of understanding. Finally we describe how CSILE's design is intended to support these more favorable school conditions.

Classroom discourse has many features that distinguish it from discourse aimed at understanding. Most class talk can be characterized as "recitation"

(Doyle, 1986). When there are discussions aimed at understanding they are generally led by the teacher. Transcripts of classroom discussion indicate that such "discussions" typically consists of a string of three-step units, each unit being made up of the following conversational moves: teacher initiates, student responds, teacher evaluates (Heap, 1985). Socratic dialogue is put forward as a model for classroom discourse, but here too the teacher gives the discussion such direction as it has and thus is likely to be the only one whose goals have substantive influence on the outcome. The students' own goals may influence how successful the discussion is, but mainly through influencing the extent of their cooperation.

When it is adaptive not to seek understanding

There is an old saying in the U.S. Army that there are three ways to do everything: the right way, the wrong way, and the Army way. This is part of a lesson often explicitly stated to recruits, that they should not try to understand why they are supposed to do this or that, because usually there is no explanation or, if there is, it is not worth knowing. Better just to do as you are told and thereby stay out of trouble.

Similar advice might be but usually is not given to students entering school. Classroom work, even when it is meaningful in its underlying intent, is often characterized by arbitrariness in the standards and procedures that most immediately confront the student. Starting every paragraph with a topic sentence, writing papers of specified length, turning assignments in on specified dates or having time allocations for school work might all represent reasonable expectations, but they are, nonetheless, arbitrary. Likewise, students would have little chance of abstracting significant principles from arbitrary procedures involving arithmetic algorithms, spelling lists, outlines in advance of writing, and the need to eliminate double negatives, "and" and "but" as first words in sentences, and prepositions as last words in sentences. But perhaps the most damaging kinds of arbitrariness involve classification and lists--six causes of the French Revolution, five steps in problem solving, four examples of symbiosis, and so on. Textbooks and student assignments are filled with such lists and classifications, which take on undue importance because of the ease with which they can be converted into test items. Even when classifications do have underlying significance, as in the case of plant and animal phyla, the value or meaning of the classification is often neglected in favor of merely teaching it as fact (Bereiter, 1992). Arbitrariness also leads to the use of mnemonics rather than reasoning--the only real aid to recall under such conditions.

Although there is a great deal of arbitrariness in school life, afflicting teachers and students alike, it is only one of a number of factors that can undermine the urge to understand. Other conditions of school life that we place in this category include: product orientation, incomprehensible texts and explanations, limited time for reflection coupled with competitive knowledge display, emphasis on reproducing authoritative statements of facts combined with disadvantages of producing interpretive accounts, overload, discontinuity of much of school work with prior knowledge, and busywork.

Product orientation. American industries are being criticized for their bias toward quantity production rather than quality (Dobyns & Crawford-Mason, 1991). American schools may be similarly criticized for their emphasis on getting out a product. Students, accordingly, cannot be blamed if they adapt in the way that adult workers adapt--by finding ways to meet production requirements with a minimum of time and effort. Although school tasks may vary considerably, and are sometimes selected by the students, they almost always center on a product--a completed workbook page, a piece of writing, a written problem solution, etc., not on understanding. Stated differently, typical school environments do not directly confront students with needs for understanding, critical examination of beliefs, and the like. What they are confronted with are essentially endless series of tasks to be done within severe time constraints. It is also fairly common in schools to reward early task completion--with the idea that students can then do other things that are more enjoyable, such as free reading or playing a computer game. Under conditions of this sort an adaptive organism will develop strategies that minimize time to complete tasks, and the most likely way to do this is by trimming away activities that do not directly yield the deliverable product.

Unintelligibility. School texts have been rendered unintelligible by various forms of simplification, including the elimination of connectives in order to obtain desired results with the application of readability formulas (Davison, 1984) and simplified drawings and representational devices that stand in the way of understanding (Engestrom, 1990). Similarly, many texts offer explanations so shallow that only knowledgeable readers might infer their deeper meaning (Armbruster, B. B., & Anderson, T. H. 1981; Armbruster, 1984; Beck, I. L., McKeown, M. G., & Gromoll, E. W. 1989). While we noted above that there is considerable evidence that students fail to pick up discrepancies in texts, this may be in part an adaptation to the presence in school texts of allusions students are not expected to understand but that are put there to avoid criticism from subject-matter experts.

Lack of opportunity for reflection. Studies have indicated that the average time a teacher waits for response to a question is a few seconds (Dillon, 1982). Students who can respond without taking time to think are thus favored. More generally, school processes that require outgoing, confident, speedy processing favor economical rather than reflective strategies. From this standpoint we might rethink the copy-delete and knowledge-telling strategies mentioned above. Their virtue is that they are highly economical. Because they are single-pass strategies it is possible to avoid going back over text, reconsidering decisions, or carrying out complex searches. They are perfect for time-constrained processing of information. Further, the information processing load is small, compared to that of more sophisticated ways of processing text (Bereiter & Scardamalia, 1984; Scardamalia, 1981). Viewed from this perspective they represent highly adaptive responses to school.

Emphasis on reproduction of information. Schools are frequently criticized for encouraging rote reproduction of information--in assignments, recitations, and tests--rather than emphasizing understanding. placing undue emphasis on reproducing authoritative statements of facts, and for discouraging interpretation. Comprehension tests are notorious for their emphasis on recall rather than understanding. But beyond the realm of multiple choice and comprehension tests there are classroom questioning routines that encourage students to reproduce authoritative statements of facts rather than to risk wrong answers that are more likely to follow from paraphrased and interpretive accounts of material. One study, for example, showed that students judged rightly that they would do better on exams if they copied notes verbatim from lectures rather than trying to put material in their own words (Fillion & Mendelsohn, 1979).

Overload. School curricula typically require that students take up a different, major topic of study every 2 to 6 weeks. Texts are frequently jammed with facts and lists so that the number of items to be committed to memory exceeds what can be learned with understanding. As a result, students attempt to learn through use of mnemonics and other cramming devices that have little long-term advantage.

Remoteness from experienced reality. Curriculum materials and teacher's explanations frequently miss the mark, providing little continuity between scientific accounts as these make sense to already sophisticated adults and accounts that start with students' naive interpretations and build on them. As a result the literature is replete with accounts of gaps between what is taught, what is understood, and everyday experiences (Anderson & Smith, 1984; Larkin, McDermott, Simon, & Simon, 1980; and Nussbaum & Novak 1976;) . In the extreme case, schooling may seem so unrelated to the world students experience that they decide one set of beliefs is true in school and another set is true of the actual world (Vosniadou & Brewer, 1987).

Busywork. Like life in the army, where meaningless tasks are contrived for the sole purpose of keeping soldiers busy and under control, schooling often involves a great deal of busywork--filling in workbook pages, playing repetitious educational games, writing out answers to questions at the ends of chapters, writing letters to imaginary recipients, and so on. Many writers have criticized the use of workbooks--the classroom's most pronounced form of busywork. As studies suggest, workbooks are designed to minimize students' needs to ask questions and in so doing favor routinized and unthinking approaches to the content they present. Their deadening effect on school content and contribution to wastage of school time have made them the focus of critical reviews (Anderson,1984). These same criticisms apply in varying degrees to other school activities such as work in activity centers and research that involves little more than copying material from encyclopedias. Such activities are seen as a necessary part of the school culture because keeping students busy is what buys time for teachers to attend to individual needs and to conduct small-group sessions--but such time is bought at the expense of keeping the majority of students engaged in activities that will frustrate efforts at understanding. In rethinking the culture of schools we must rethink the whole one-to-thirty, teacher-learner paradigm that makes busywork so difficult to eliminate.

Powerlessness and low probability of success. Conditions where there is no anticipation of success are also candidates for conserving the mental effort that might otherwise go into understanding. Literature on management suggests that while managers would seemingly be the ones to experience most stress, due to the level of responsibility they bear, those who exert little control over situations experience more stress (Marmot, 1986; Marmot, M.G., Smith, D., Davey Smith, G., Stansfeld, S., 1991). Generalizing from such a finding, expending effort when one has little control or chance for success may simply increase frustration. A more adaptive approach would reserve efforts for spheres of activity where one has more control over outcomes.

Redesigning Classrooms to Make Understanding Adaptive-

Although the conditions discussed in the preceding section have not generaly been thought of in terms of their effect on understanding, most of them have been recognized as undesirable. For generations there have been reform efforts aimed at remedying these conditions and thereby making schooling a more reasonable process. Given the limited success of these efforts we must ask whether the way to turn schools into institutions that encourage understanding is to focus on the elimination of negative attributes.

Notice that all the school conditions we have been discussing are ones in which some action or condition is presented to students and the issue is how they will respond to it--either my trying or not trying to understand. Absent from these considerations is any situation in which the students pursue understanding by their own initiative.

Real school reform, we suggest, should not so mcuh focus on making schooling conducive to understanding as on making understanding the focus of schooling. That is what we have been trying to do in developing CSILE as an overall approach to education. Making understanding the focus of schooling sounds so obvious and reasonable that it is difficult to realize what a radical change this means for the design of education.

The greatest change, we believe, will come from restructuring classroom discourse to give priority to progressive inquiry, with advancement of collective knowledge highly valued. Conventional schooling, by comparison, places undue emphasis on individual initiative and time- and space-limited discourses. Individual students all work on the same task, with no distribution of responsibilities or building on each others' inputs. When ideas are recorded, they are retained in individual files, and there is little continuity from one activity to another. Thus many contributions to understanding go unrecognized, with no corpus of material to represent a groups' advances, to return to for analysis and refinement, or to provide a basis for engaging others working on common problems beyond the school walls.

In the present context, CSILE is best viewed as a discourse medium. As explained in more detail elsewhere (Scardamalia & Bereiter, 1992, 1993), CSILE runs on networked computers, usually 8 to a classroom. It provides a single, communal database into which students may enter various kinds of text and graphic notes. They can retrieve notes by others and comment on them, with authors being notified of comments, link notes to one another, or create group discussion notes (which will be illustrated later). CSILE-mediated discourse can be carried on in any or all academic areas, limited only by the availability of machine time.

At present, CSILE is being used in about a dozen schools, with sites as widely distributed as Baffin Island, NWT, Cedar Rapids, Iowa, Oakland, California, and Eanes, Texas, and encompassing students from substantially below to substantially above grade levels in performance on standardized achievement tests. CSILE has been used in a variety of curricular areas, including social studies, art, history, science, geography, literature, and mathematics. Limitations of machine time, however (each student typically gets

30 minutes a day on a computer), have generally meant that at any given time only one unit or subject is being worked on via CSILE.

There are no set patterns for CSILE use. Teachers work CSILE into the curriculum in a variety of ways. (Different models of use are compared in Bereiter & Scardamalia, in press, and Lamon, Lee & Scardamalia, in press). In some cases a unit will follow a definite sequence of activities. For instance, it might begin with a videotape, followed by whole-class discussion; then students will individually enter questions and study plans as CSILE notes; then they will do individual reading, entering what they learn as notes which others may comment on; whole-class discussions or readings will intervene; finally, selected text and graphic notes may be printed out and displayed on a bulletin board. In other cases, students will work in small groups and plan their own work, with only general guidance from the teacher. Information brought into CSILE notes by students may come from any sources: books, experimental observations, interviews, electronic media.

How CSILE is intended to restructure classroom discourse can best be understood by comparing it to two other forms of discourse: ordinary classroom discussion and electronic mail. In ordinary classroom discourse the teacher is pivotal. Even in relatively open discussion, students typically address the teacher. In more controlled discussion, as previously noted, the teacher typically initiates and ends each discourse segment, with a student supplying the intervening step, which usually consists of response to a question. In contrast to this central role, the teacher in CSILE discourse functions mainly as a participant in discourse, not obligated to respond to whatever is said. (The teacher does, however, usually set the broad topic and general nature of what is to be accomplished in the curricular unit forming the basis of a discourse.)

Electronic mail is gaining interest in many schools because it also removes the teacher from the center, allowing students to communicate directly with each other and, increasingly, with people elsewhere. One of the difficulties we have had in getting the idea of CSILE across to teachers is that they tend to think of it as a variety of electronic mail and then find it not very well suited to that purpose. For, although CSILE is designed for communication within an across classrooms and outward to other places, it differs fundamentally from electronic mail in that it is not a person-to-person medium. Notes entered into the communal database are not notes <u>to</u> anyone, they are <u>contributions</u> to some collective knowledge-building effort. The only way to communicate directly with anyone is by writing a comment on their note, and this comment itself becomes a part of the community database, available for comment by others. Thus, instead of addressing the teacher, as in conventional class discussion, or addressing other individuals, as in electronic mail, students using CSILE as a medium are encouraged to address issues, problems, arguments, and the like.

Thus, in CSILE's communal database collective knowledge--as opposed to school exercises, activities, or private interests--is the center of attention. Specialized note writing environments are designed to engage students in conjecture, theory building, explication of confusions, and analysis rather than regurgitation of information. Our goal is to ensure that discourses are open and decentralized, replicating for school students much of the progressive inquiry supported by publication in scholarly journals (see Scardamalia & Bereiter, in press). The teacher's own knowledge does not curtail what is to be learned or investigated. Teachers can contribute what they know to the discourse, but there are other sources of information. The teacher remains the leader, but the teacher's role shifts from standing outside the learning process and guiding it to participating actively in the learning process and leading by virtue of being a more expert learner. Students are expected to formulate their own problems of understanding and to pursue them in a progressive manner, formulating new higher-level problems as they go. We are continually modifying and adding functionality to CSILE is in order to encourage such knowledge-building activity.

When students are at work on knowledge problems in CSILE, questions that push against the limits of current knowledge assume a natural importance. In the words of one student "I am discovering gold (knowledge) that has never been discovered before for me. A new understanding. ..." In Table 1 we present an example of students engaged in an extended text-graphic discourse with commentary aimed at understanding. [1] Students set out ideas with the expectation that these will be improved in the course of working on them, and with appreciation that their ideas are ill-formed, so a wide variety of ideas can advance their understanding, not just those that violate expectations. Accordingly, they generate hypotheses (MT - "My Theory"), note constraints and

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[1] This episode is based on work conducted by Jim Hewitt and Jim Webb in a CSILE-supported grade 5/6 class.

related problems, and actively seek information that will help them improve their theories (INTU - "I Need To Understand") .

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In another series of discussion notes in the CSILE database, students could be seen "unlayering" problems, iteratively applying a "How-does-it-work?" schema in a search for underlying causes. The group begins by identifying the problem "Why do you have to change the denominator to add fractions?" In the course of trying to understand that problem they discover a related problem: "Why do you have to change the denominator when you add fractions but not when you multiply them?" In their attempt to solve this problem they discovered yet another problem: "Why do fractions get smaller when you multiply them?" Note that without any intervening activity that violates their assumptions, and without help from more knowledgeable others, they think through problems enough to note insufficiencies in their own explanations. They literally identify additional problems to be understood and set out to understand them. It is through their own inventions--noting that what they understand does not provide sufficient explanation--that they make advances.

Although this behavior seems to be inconsistent with Schank's view that explaining is a response to "failed expectations" and with "impasse-driven" views of learning in general, there is an important difference in situation that should be noted. The situations that Schank and others consider are usually those in which people are engaged in a practical activity and encounter some unexpected obstacle or turn of events. People in effect take time out from the main activity in order to seek understanding, which will enable them to proceed more successfully with the main activity. But in a CSILE classroom, explanation-seeking is the main activity. The problems students are trying to solve are problems of understanding. Surprises and impasses may occur; a new fact may come to light, for instance, that invalidates a current explanation, or the student may realize that something else must be understood before the main knowledge problem can be solved. In these cases learning will occur just as impasse-driven learning views would predict. So there is no basic contradiction; but it is important to realize that understanding can be a goal pursued in its own right, as well as a response to surprise or failure. Pursuing understanding is, after all, what many impasse-driven learning theorists do for a living.

Our efforts with CSILE do not speak to the question of whether explanation-seeking is a natural, innately motivated activity. We believe the culture of schools needs to be changed before we can determine if schools or children's psychological makeup is at issue when we give evidence of nonpursuit of understanding. Schools typically do not afford the luxury of progressive refinement of problems driven by the goal of understanding for its own sake. There is too much curriculum to get through, so that information is pumped at students too fast for them to have a chance to wonder about things. The findings to be presented below do, however, suggest that in CSILE cultures where understanding is highly valued and conditions are conducive to it, students show greater evidence of pursuing understanding than typical school experience would lead one to expect.

Findings suggestive of CSILE's role in the development of understanding

The strategy we have used to address issues particular to the role of understanding is to present students with material that is, by age-adjusted standards (readability levels, problem-solving difficulty), more demanding than typically dealt with successfully at their age. For this purpose a "difficult texts" assessment device was designed that required students to read texts and to solve transfer problems demonstrating in-depth understanding of those texts (Lamon, Chan, Scardamalia, Burtis, & Brett, 1993; Scardamalia et al, 1992). As predicted, CSILE students provide more sophisticated solutions to transfer problems, and recall more of the original text as well. In like manner, CSILE and non-CSILE students were required to convey their understanding of difficult concepts (e.g., continental drift) through use of graphics (via pencil and paper rather than computer to eliminate a possible computer advantage for CSILE students). CSILE-student graphics demonstrate greater conceptual understanding as evidenced in their more thorough explanations involving indications of movement, underlying processes, before-after perspectives, and so forth (Gobert, Coleman, Scardamalia, & Bereiter, 1992).

On another measure we looked for depth of explanations in students' written reports. Students wrote essays on what they had learned after a unit of study. Learning for CSILE students is more frequently judged toward the high end of the scale ("elaborated description of the topic area as a system"), whereas the work of control students is more frequently judged toward the low end ("isolated bits of information"). Also, CSILE and non-CSILE students keep writing, mathematics, and science portfolios and write comments on their selections and on the selection of a peer. To a significantly greater extent than control students, students using CSILE are able to provide detailed accounts of gains in understanding resulting from their engagement in the work represented in their portfolios (Lamon, Abeygunawardena, Cohen, Lee, & Wasson, 1992).

Finally, we would expect CSILE students to have beliefs about learning that reflect mature views of understanding. For example, we would expect them to appreciate that understanding requires self-directed effort, that good marks are not a perfect reflection of learning, that uncertainty and unanswered questions can be signs of progress, and so forth. In line with such expectations CSILE students, to a significantly greater degree than their control counterparts, show more mature views of learning. (For more detailed analysis of the above results see Lamon, M., Chan, C., Scardamalia, M., Burtis, J., & Brett, C. 1993).

In summary, CSILE students consistently outperform control students in ways that suggest more understanding. [2] Further, the longer students spend working with CSILE the better the results. For example, students who spend two years in CSILE classrooms show significantly greater achievement than their first-year counterparts, and there is another increment in the third year (on

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[2]Significant results favoring CSILE students have been found on other measures, including standardized achievement tests (see Scardamalia, Bereiter, Brett, Burtis, Calhoun et al., 1992), but we do not review these here.

measures of the sort presented above). CSILE results are also distinct, to our knowledge, in that there is equal engagement by students at low and high ends of the ability spectrum, and by females and males (in the sense of numbers of notes contributed to the database) (Scardamalia & Bereiter, in press).

Conclusion

We have been impressed with how our own thinking has changed as we have become increasingly sensitive to an adaptationist perspective. From this perspective students' minimalist strategies are not consciously aimed at beating the system. These students are doing what adaptive organisms always do, behaving in ways that are locally optimal, given the environment (cf. Anderson, 1990). We argue that efforts at school restructuring should focus on altering classroom conditions that make minimalist strategies adaptive. Toward this end we analyze conditions of schooling that inhibit efforts at understanding , and contrast these with conditions that encourage students to pursue understanding by their own initiative. The latter analysis is based on our experience in developing and implementing a computer-based system (CSILE) for information sharing and knowledge advancement. In an effort to determine whether students in CSILE-based classrooms benefit from environments that place understanding center-front the CSILE team has conducted a series of investigations requiring demonstration of greater understanding in students' approach to and comprehension of difficult texts, in their ability to explain difficult concepts through use of graphics, in their writings and selections of material aimed at demonstrations of learning, and finally in their understanding of the active role they must play if they are to take charge of their own understanding. On these counts students in CSILE-supported classrooms outperform students in control classrooms, leading us to conclude that it is possible to create school environments that give understanding a central role and that the benefits from doing so are considerable.

Table 1

Example of CSILE Discussion Note[1]

Topic: Human Biology

Keywords: biology, cell function.

P: How does a cell function? {AR}

MT: I think a cell functions by oxygen coming into the cell and the cell then can do it's work by breathing {AR}

MT: I agree with your theory but when the cell functions I don't think it is breathing, I think that the oxygen your breathing in is doing it. (JD)

MT: I think a cell functions by the "things" inside itself. (orgenelles) (AK)

MT: (MS)

INTU: How the oxygen gets into the cell, if the cell really does breath oxygen. {AR}

MT: I don't think that cells breath oxygen, I just think that the cells need oxygen to do its work. But if the cells do breath oxygen, I think that there is some kind of a tube in the cell that helps the cell get the oxygen it needs. (AK)

NI: I found out that the cell takes food and oxygen in through the membrane. This happens regularly. The cell then changes the food and oxygen into energy. It uses the energy to do it's work. {AR}

INTU: How the food and oxygen gets to the cells membrane. {AR}

MT: I think there are very small tubes that lead to each cell and the food and oxygen goes down those tubes and into the cell through the cells membrane. {AR}

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[1] Key: P = Problem; MT = My Theory; INTU = I Need To Understand; NI = New Information. Letters in brackets are initials of students authoring the contributions.

References

Anderson, C.W., & Smith, E.L. (1984). Children's Preconceptions and Content-Area Textbooks. In Gerald G. Duffy, Laura R. Roehler, & Jana Mason (Eds.), Comprehension instructions. Perspectives and suggestions (pp. 187-201). New York, NY: Longman.

Anderson, J. R. (1990). The adaptive character of thought. Hillsdale, NJ: Erlbaum.

Anderson, L. (1984). The Environment of Instruction: The Function of Seatwork in a Commercially Developed Curriculum. In Gerald G. Duffy, Laura R. Roehler, & Jana Mason (Eds.), Comprehension instructions. Perspectives and suggestions (pp. 93-103). New York, NY: Longman.

Armbruster, B.B. (1984). The Problem of "Inconsiderate Text". In Gerald G. Duffy, Laura R. Roehler, & Jana Mason (Eds.), Comprehension instructions. Perspectives and suggestions (pp. 202-217). New York, NY: Longman.

Armbruster, B. B., & Anderson, T. H. (1981). Content-area textbooks (Reading Education Report No. 23). University of Illinois, Center for the Study of Reading.

August, D. I., Flavell, J. H., & Clift, R. (1984). Comparison of comprehension monitoring of skilled and less skilled readers. Reading Research Quarterly, 20, 39-53.

Beck, I. L., McKeown, M. G., & Gromoll, E. W. (1989). Learning from social studies texts. Cognition and Instruction, 6, 99-158.

Bereiter, C., & Scardamalia, M. (1987). The psychology of written composition. Hillsdale, NJ: Lawrence Erlbaum Associates.

Bereiter, C., & Scardamalia, M. (1992). Two Models of Classroom Learning Using a Communal Database. In S. Dijkstra (Ed.), Instructional models in computer-based learning environments (NATO-ASI Series F: Computer and systems sciences) (pp, 229-241). Berlin: Springer-Verlag.

Berzonsky, M.D. (1971). The role of familiarity in children's explanations of physical causality. Child Development 42(2), 705-715.

Brown, A. L., & Day, J. D. (1983). Macrorules for summarizing text. Journal of Verbal Behaviour, 22, 1-14.]

Brown, A. L., Day, J. D., & Jones, R. S. (1983). The development of plans for summarizing texts. Child Development, 54, 968-979.

Davis, R. B. (1981). The postulation of certain specific, explicit, commonly-shared frames. Journal of Mathematical Behavior, 3 (1), 167-201.

Davison, A. (1984). Readability Formulas and Comprehension. In Gerald G. Duffy, Laura R. Roehler, & Jana Mason (Eds.), Comprehension instructions. Perspectives and suggestions (pp. 128-143). New York, NY: Longman.

Dillon, J.T. (1982). The multidisciplinary study of questioning. Journal of Educational Psychology, 74, 147-165.

Dobyns, L. and Crawford-Mason, C. (1991). Quality or else. Boston: Houghton Mifflin.

Eichinger, D. C., Anderson, C.W., Palincsar, A.S., & David, Y.M. (1991). An Illustration of the Roles of Content Knowledge, Scientific Argument, and Social Norms in Collaborative Problem Solving. Paper presented at the annual meeting of the American Educational Research Association, Chicago, ILL.

Engestrom, Y. (1990). Learning, working and imagining: Twelve studies in activity theory. Helsinki: Orienta-Konsultit Oy.

Fillion, B., & Mendelsohn, D. (1979). A pilot investigation into the effects of writing on learning (Unpublished report. Ontario Institute for Studies in Education.)

Garner, R. (1980). Monitoring of understanding: An investigation of good and poor readers' awareness of induced miscomprehension of text. Journal of Reading Behavior, 12, 55-63.

Garner, R. (1987). Metacognition and reading comprehension. Norwood, NJ: Ablex.

Gobert Wickham, J., & Coleman, E. B., Scardamalia, M., & Bereiter, C. (1993, April). Fostering the development of children's graphical representation and causal/dynamic models through CSILE. Paper presented at the annual meeting of the American Educational Research Association, Atlanta, GA.

Lamon, M., Abeygunawardena, H., Cohen, A., Lee, E., & Wasson, B. (1992, April). Students' reflections on learning: A portfolio study. Paper presented at the American Educational Research Symposium, Peer Collaboration for Reflective Thinking, San Francisco.

Lamon, M., Chan, C., Scardamalia, M., Burtis, J., & Brett, C. (1993, April). Beliefs about learning and constructive processes in reading: Effects of a computer supported intentional learning environment. Paper presented at the annual meeting of the American Educational Research Association, Atlanta, GA.

Markman, E. M. (1979). Realizing that you don't understand: Elementary school children's awareness of inconsistencies. Child Development, 50, 643-655.

Markman, E. M. (1981). Comprehensive monitoring. In W. P. Dixon (Eds.), Children's oral communication skills (pp. 61-84). New York: Academic Press.

Marmot, M. G. (1986). Social inequalities in mortality: The social environment. In R. G. Wilkenson (Eds.), Class and health: Research and longitudinal data. (pp. 21-33). London: Tavistock.

Marmot, M.G., Smith, D., Davey Smith, G., Stansfeld, S., et al. (1991, June). Health inequalities among British civil servants: the White hall II study. The Lancet, 3337 , 1387-1393.

Nussbaum, J., & Novak, J.D. (1976). An assessment of childrens' conceptions of the earth using structured interviews. Science Education, 60, 535-550

Paris, S. G., & Myers, M. (1981). Comprehension monitoring, memory, and study strategies of good and poor readers. Journal of Reading Behavior, 13, 5-22.

Pascual-Leone, J. (1976). Metasubjective problems of constructive cognition: Forms of knowing and their psychological mechanism. Canadian Psychological Review, 17, 110-125.

Pascual-Leone, J., & Goodman, D. (1979). Intelligence and experience: A neopiagetian approach. Instructional Science, 8, 301-367.

Scardamalia, M. (1977). Information processing capacity and the problem of horizontal decalage: A demonstration using combinatorial reasoning tasks. Child Development, 48, 28-37.

Scardamalia, M. (1981). How children cope with the cognitive demands of writing. In C. H. Frederiksen & J. F. Dominic (Eds.), Writing: The nature, development and teaching of written communication (Vol. 2, pp. 81-103). Hillsdale, NJ: Lawrence Erlbaum Associates.

Scardamalia, M., & Bereiter, C. (1984). Development of strategies in text processing. In H. Mandl, N. Stein, & T. Trabasso (Eds.), Learning and comprehension of text (pp. 407-428). Hillsdale, NJ: Lawrence Erlbaum Associates.

Scardamalia, M., & Bereiter, C. (1987). Knowledge telling and knowledge transforming in written composition. In S. Rosenberg (Ed.), Advances in applied psycholinguistics: Vol. 2. Reading, writing, and language learning (pp. 142-175). Cambridge: Cambridge University Press.

Scardamalia, M., & Bereiter, C. (1992). An architecture for collaborative knowledge-building. In E. De Corte, M. Linn, H. Mandl, & L. Verschaffel (Eds.), Computer-based learning environments and problem solving (NATO-ASI Series F.: Computer and Systems Sciences, Vol. 84, pp. 41-66). Berlin: Springer-Verlag.

Scardamalia, M., & Bereiter, C. (in press). Technologies for knowledge-building discourse. CACM Special Issue: Technology in Education.

Scardamalia, M., Bereiter, C., Brett, C., Burtis, P.J., Calhoun, C., & Smith Lea, N. (1992). Educational applications of a networked communal database. Interactive Learning Environments, 2(1), 45-71.

Schank, R.C. (1986). Explanation patterns: Understanding mechanically and creatively. Hillsdale, NJ: Earlbaum

Schoenfeld, A. H., & Herrmann, D. J. (1982). Problem perception and knowledge structure in expert and novice mathematical problem solvers. Journal of Experimental Psychology: Learning, Memory and Cognition, 8, 484-494.

Shayer, M., & Wylam, H. (1981). The development of the concepts of heat and temperature in 10-13 year olds. Journal of Research in Science Teaching, 18(5), 419-435.

Van Lehn, K. (1990). Mind bugs: The origins of procedural misconceptions. Cambridge, MA: MIT Press.

Vosniadou, S., & Brewer, W. F. (1987). Theories of knowledge restructuring in development. Review of Educational Research, 57, 51-67.

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