Theory Reform Caused by an Argumentation Tool

Kurt VanLehn
Recently, software aids have been developed for formulating and managing arguments. Most of these programs are combinations of text editors and databases. This paper concerns one such system, called NoteCards. The paper discusses two incidents where using the system uncovered major flaws in the arguments. These discoveries were quite unexpected. This paper discusses these two incidents and tries to ascertain why such a simple tool had such a profound impact and what the tool’s future might be.
Theory Reform Caused by an Argumentation Tool

Kurt VanLehn

ISL-11 July 1985 [P85-00102]

© Copyright Xerox Corporation 1985. All rights reserved.
Theory Reform Caused by an Argumentation Tool

Kurt VanLehn

Abstract

Recently, software aids have been developed for formulating and managing arguments. Most of these programs are combinations of text editors and databases. This paper concerns one such system, called NoteCards. The paper discusses two incidents where using the system uncovered major flaws in the arguments. These discoveries were quite unexpected. This paper discusses these two incidents and tries to ascertain why a such a simple tool had such a profound impact and what the tool's future might be.
Theory reformulation caused by an argumentation tool

Kurt VanLehn

There are many projects whose goal is to produce a network of well-reasoned arguments in support of some assertions. Examples of such networks are a legal brief, a market analysis or a scientific theory. Until recently, computer technology for developing such networks was concerned mostly with the acquisition of information to feed into the arguments. Information retrieval systems help the lawyer find precedents. Survey instruments and statistical packages help the market analyst quantify market forces. Computer-driven instruments line the benches of the physical scientist's laboratory. Such tools help find the facts upon which the arguments rest, but they don't help the reasoner invent, record, manage or modify the arguments themselves. For manipulating arguments, these professionals have had to rely on paper technologies, such as index cards and file folders, or their electronic analogs, text editors and file systems.

Recently, software aids have been developed for formulating and managing arguments. Most of these programs are combinations of text editors and databases. This paper concerns one such system, called NoteCards, which is being developed at Xerox's Intelligent Systems Laboratory. The paper reports the authors's experience in using the system. It discusses two incidents where using the system uncovered major flaws in the arguments. These discoveries were quite unexpected. The expectation had been that NoteCards would make argumentation easier, but not that it would change its quality.

This paper discusses these two incidents and tries to ascertain why a such a simple tool had such a profound impact and what the tool's future might be. The discussion and analysis is necessarily informal and even anecdotal at times. Such a treatment cannot, of course, substitute for careful experimentation. However, it seems worth reporting these incidents now because they raise certain interesting, non-obvious issues. This informal presentation of the issues may lay the groundwork for more formal studies.

The two incidents occurred a month apart. The second one is simpler to describe, so it will be presented first. Before that, a little background on my project is necessary.

Background

The project is to develop a psychological theory of how people learn procedures, such as arithmetic procedures, clerical procedures, or procedures for analyzing electronic circuits (see VanLehn, 1983a, for a synopsis). The main data are a large collection of systematic errors (called bugs) that were observed in...
the behavior of 114 elementary school students who were learning arithmetic. Most bugs can be explained more than one way depending on what hypotheses one makes about the learning process. The main job of argumentation is to contrast the explanatory power of various sets of hypotheses. Metaphorically speaking, the theorist takes several sets of hypotheses and sees how many bugs each can explain.

In practice, the argumentation does not contrast multiple sets of hypotheses. Instead, a divide and conquer strategy is used. The overall question — how are procedures learned? — is divided into a set of issues. Each issue has several alternative hypotheses to explain it. One starts with very general issues, such as “Do students learn from worked example exercises, or from analogies to familiar procedures, or from written descriptions of the procedure, or what?” Depending on which hypothesis wins the argument, more specific issues are formulated, e.g., “Given that students learn procedures from worked examples, how do they learn conditional branches?” (A conditional branch is a chunk of procedure of the form: If such-and-such then do X else do Y.) The relationship between issues, hypotheses and subissues will be discussed later in detail. The point here is only that instead of formulating a huge argument that contrasts whole sets of hypotheses, one considers a set of issues and for each issue, formulates an argument contrasting several individual hypotheses.

The two incidents of NoteCard-induced theory reformulation are complementary. One incident concerns the structure of intra-issue reasoning, and the other incident concerns the structure of inter-issue reasoning. To put it differently, the first incident concerns the structure of an argument about a single issue, i.e., how to compare several hypotheses and choose a winner. The second incident concerns representing the relationships between issues.

Intra-issue argumentation

NoteCards deliberately does not force an argument structure on the user. In this respect, it differs from ThinkTank and other outlining tools which force the user to employ a tree structure. This extra flexibility allows users to use multiple argument structures and to change their arguments from one structure to another. The incident to be described in this section was precipitated when the theory’s arguments were converted from one format (a tree structure) to another (a matrix structure).

The NoteCards system is based on a simple idea: an electronic 3-by-5 card. The database is a set of "notecards." Figure 1 shows several notecards as the user normally sees them on the screen. A notecard has a title, which shows in the dark bar on the top of the card. The body of a notecard is text and/or graphics. All the notecards shown in figure 1 have textual bodies. A notecard’s body may contain pointers. In the middle card of figure 1, there are four pointers. Pointers have labels. The label of the first pointer is "Remark," and the label of the second pointer is "Rebuttal." The other two pointers are labelled as well, but the user has chosen a display format for these pointers that does not show the labels. There are no contraints on the vocabulary of pointer labels; the user may create new labels as well. The destination of a pointer is another card. The destination of the first pointer in the middle card is the top card. The destination of the other three pointers is the bottom card. There are no contraints on the topology of pointers. A card can point to itself or any other card.
Each card is an instance of a WYSIWYG editor (what you see is what you get) that uses a mouse as a pointing device. When the user points at a pointer and clicks the mouse button, the card that is the destination of the pointer is fetched from the notecard database and displayed on the screen. This allows one to flip quickly through cards. Many other facilities are provided by NoteCards, but the preceding brief introduction will suffice for now.

As mentioned earlier, a change in the format of arguments led to uncovering flaws in the theory. The old format was a tree. Figure 2 displays such a tree as a schematic outline. This tree structure reflects a standard rhetorical structure. The format has the advantage that breadth-first traversal of the tree is an expositional sequence that makes sense. In fact, the original NoteCards database was constructed from a 328-page document (VanLehn, 1983b) whose expositional structure was a breadth-first traversal of the argument trees. That is, each chapter was a discussion of a single issue. A chapter began with a statement of the issue and a list of the competing hypotheses. Each of the remaining sections of the chapter discussed a single hypothesis, giving the arguments for and against it. The document had about 20 chapters, with three to seven hypotheses per chapter. Because the document was carefully structured and the NoteCards format was chosen to reflect this structure, it was easy to convert the document into a NoteCards database. It took only ten days.

The incident occurred while new hypotheses were being added to the theory. A certain issue already had four hypotheses. Three more hypotheses had been invented. Their empirical implications looked promising, although a little confusing. Putting the new hypotheses into the NoteCards system should have clarified which of the seven hypotheses was the best. However, the resulting tree structure did not make it much easier to tell which hypothesis was the winner. The actual empirical facts (i.e., bugs) dangled off the leaves of a bushy tree of notecards. A summary card was needed that would show the hypotheses and facts in a compact way. For each fact and each hypothesis, it should show whether the fact supported the hypothesis or not. The obvious organization was a Cartesian product (see Figure 3).
the blank cells, and yet, the results were quite surprising. All three of the new hypotheses turned out poorly. Of the four old hypotheses, the one that was thought best actually turned out quite badly. A previously rejected hypothesis turned out best. In short, sloppy reasoning, abetted by a poor rhetorical organization, allowed the suppression of a winning hypothesis. The new matrix organization uncovered the mistakes, leading to an improved theory.

This incident was not unique. Several reversals of the same kind occurred as the rest of the arguments were converted to matrix format. That these errors could remain undetected for several years is even more amazing when one considers how many people had read or listened to the arguments. The implications of this incident will be discussed after the second incident has been described.

**Inter-issue argumentation**

A common device in the argumentation is to use an independently motivated hypothesis to help defend one of the hypotheses under discussion. For instance, if A and B are competing hypotheses, and X is the winning hypothesis of some other issue's competition, one argues "X and A together predict F, whereas X and B predict not-F. Since F is empirically true, A is a better hypothesis than B." The argument for A assumes X. This is one kind of inter-argument relationship, the most common one. This inter-issue relationship was represented in NoteCards by having the argument cards for A and B have a pointer to X labelled "premise."

Explicitly representing inter-issue relationships was a major reason for converting the document to NoteCards. As the theory changed, it was important to know which arguments depended on which hypotheses. For instance, if hypothesis X is refuted by new evidence, then one must retract the arguments that have X as a premise. This was difficult given just the document. Although one could open the document to the section that describes hypothesis X in order to see the arguments for and against it, the document was not cross-indexed in such a way that one could find all the arguments that depended on X. NoteCards automatically provides such a cross-index. Attached to the card for X is a list of all the pointers that point to X. This cross-index makes it easier to revise the theory.

After a few weeks of theory revision, it seemed likely that these inter-issue pointers could provide a nice geometric summary of the theory as a whole. NoteCards can automatically construct, layout, and display a directed graph whose nodes are card titles and whose links correspond to pointers running between a pair of cards. This facility is called a browser. Similar facilities in programming environments have been found to be extremely useful in summarizing complex programs. It seemed likely that browsing the NoteCards database using the premise pointers would yield a helpful overview of the theory.

When an attempt was made to browse the database, an unexpected property of the argumentation was discovered: the graph created by the browser was disconnected. There were sets of issues that were totally unrelated to other sets. Intuitively, this shouldn't be so. Because the issues are all part of the same theory, they must relate somehow. The browser revealed that some essential inter-issue relationships had not been made explicit.
This touched off a examination of the epistemology of inter-issue relationships. It was discovered that important assumptions had been made without mentioning them anywhere. The assumptions were all of a certain kind: a large issue was decomposed into smaller issues. For example, the large issue "what is the student's mental representation of the skill they are learning?" was decomposed into three smaller issues:

1. What is the representation of perceptual knowledge about the skill's environment, e.g.,
   - For the subtraction skill, a grammar for the multicolumn notation.
   - For algebra, a grammar for algebraic equations.
2. What is the representation of procedural knowledge, e.g.,
   - For subtraction, a procedure for writing and scratching out digits.
   - For algebra, a procedure for selecting algebraic transformations.
3. What is the representation of factual knowledge, e.g.,
   - For subtraction, a table of number facts such as 7-5 = 2.
   - For algebra, a table of facts such as "+ is the opposite sign of +".

The division of task-specific knowledge into notational, procedural and factual knowledge was never mentioned explicitly in the document. There were several such decompositions, none of which had been recognized in the document. The NoteCards system browser revealed that these decompositions were needed in order to complete the argumentation.

The obvious cure was to add a new type of notecard, called a decomposition, to describe the division. When this was done, it became clear that these decompositions were doing almost as much 'work' as the hypotheses. At that time, there were 36 issues: seven were handled by decomposition and 29 were handled by competitive argumentation among hypotheses. Clearly, these decompositions needed to be subjected to closer scrutiny. The best way would be to hold competitions among alternative decompositions. It didn't take long to figure out alternative decompositions to the seven original ones (which is significant in itself).

One of the new, alternative decompositions turns out to have very interesting properties. It is an alternative to the decomposition mentioned above. This decomposition is called the annotated grammars decomposition because it replaces two knowledge representations — the notational grammar and the procedure, which are parts 1 and 2 in the list above — with a unified representation called an annotated grammar. Whereas grammars, procedures and tables of facts are common representations in computer science, annotated grammars are new. Although it is not worth explaining the technical details in this paper, it seems now that annotated grammars are a much better model of student's knowledge structures, even for the supposedly "procedural" skills of arithmetic! The annotated grammars decomposition is a major, and welcome, revision to the theory.

The discovery of the annotated grammars decomposition was provoked by an observed incompleteness in the argument structure of the theory. NoteCards made observing this incompleteness easy, and perhaps even inevitable. By the way, once the seven new decomposition issues were added to provide a home for the new decomposition competitions, the browser created a connected graph (see figure 4).
The titles with a "C" suffix label the decomposition issues. Without them, the graph would be quite disconnected.

---

Insert figure 4 about here.

---

Discussion

Paper note cards have been used for decades for organizing arguments, although I did not happen to use them in developing my theory. Although NoteCards may be faster and more convenient than paper note cards, but is there any reason to believe that NoteCards encourage better quality argumentation than paper note cards? That is, would the incidents just described have happened if I had used paper note cards instead of NoteCards? There are several reasons to doubt that they would have. First, because paper note cards are three-dimensional objects, the easiest way to implement scratch organizations of paper note cards is to arrange them spatially. However, when there are more than about 100 note cards, this gets cumbersome. (Incidently, there are about 800 NoteCards in my database.) When there are many paper note cards, it is inevitable that they are arranged spatially along their thinnest dimension: they are filed in a file box. The most complex topology that can fit in a single dimension is a tree. Paper note cards encourage dendritic organizations, unless the person is working with a small number of cards. In short, when one is fooling around with various scratch organizations, paper note cards don't encourage one to search the whole space of possible organizations. To put it more poetically, I doubt that I would have tried a matrix format for arguments if I had been using paper note cards. Consequently, the theory would still contain many flawed arguments.

There is no doubt that NoteCards encourages one to "fool around with scratch organizations," Is this good? I will argue that it is, by using an analogy to text editing. One often-heard complaint about modern text editors is that they encourage writers to fool around with the format of the text, and thus slow the document preparation process down. That is, writers get too engaged in making their document look pretty. Not only that, many writers are bad at it. Their documents are uglier and harder to understand than documents that are professionally typeset. The complaint goes on to suggest that writers should either be trained in how format text quickly and effectively, or they should leave text formatting to those who are trained at it. Superficially, there seems to be a analogy here to NoteCards, which encourages thinkers to explore organizations of their arguments. The analogy says that fooling with argument organizations will just waste the thinker's time. Someone else should do it. However, there is a cadre of professional argument-organizers who are the analogs of printers and graphics designers. Someone there be such a cadre. The organization of arguments is too strongly coupled to their content. The content, the format of text is weakly coupled, so professional text formatters can and do it. The idea is a little different: argumentation has an organization whether one likes it or not. Likewise, note cards are set like it or not. Someone has to give the arguments a good organization. And that
someone must be the thinker who is responsible for the argument's content. In short, exploring argument organizations is a necessary activity, not a waste of the thinker's time.

NoteCards encourages a particular kind of exploration. To see this, let's compare the process of organizing arguments using NoteCards with the same process using paper note cards. With paper note cards, a spatial organization is external to the content of the note cards. You don't have to change what the card says in order to move it from one file to another. On the other hand NoteCards' browser is driven by the content of the cards, namely the pointers that are part of their texts. To reorganize a browser, you must change the cards' content. To put it differently, NoteCards' organizations are emergent properties of the content of the arguments; they are not imposed from the outside. In retrospect, both the tree organization that I used for my arguments in the document and the list-like chapter structure were external organizations. They were so decoupled from the content of the arguments that I was able to fool myself (and the readers!) into believing that more was shown than actually was shown. NoteCards' emphasis on emergent organizations makes it harder to fool oneself.

Perhaps the hardest job that a theorist has is to discover the assumptions that he or she is making. Goodman (1955) has pointed out, in connection with his famous Grue-Bleen example, that important scientific assumptions may hide in the very vocabulary one uses to think about the theory. Uncovering such assumptions is so difficult that any aid, even indirect aid, would be welcome. NoteCards seems to provide such aid. At least, it helped me uncover a class of assumptions, namely the decomposition issues, that lay deeply buried in the technical vocabulary of computer science and mathematics. The discovery of the annotated grammars decomposition is a case in point.

What happens to a NoteCards database eventually? Mine is too big to publish, even as a book. One wonders if it is worth the effort to type in all those NoteCards when all one can hope to gain is a better theory (as if that weren't enough!). There are several answers, ranging from mundane to futuristic. First, it isn't all that much typing. It took only ten days to get my database started. Second, NoteCards has facilities for stringing together cards into a single document. Thus, with a little extra effort, one can obtain a rough draft of a paper, or perhaps several papers.

On a more personal note, I find that NoteCards falls into a natural niche that is midway between publications and lab notes. Publications have to be carefully worked over to be both an accurate, consistent presentation of the theory and an understandable one. On the other hand, lab notes are private memoranda, where ideas are worked out in rough. One's recent lab notes are often based on assumptions that contradict earlier lab notes, reflecting the process of theory revision. As a whole, lab notes are inconsistent and sometimes vague, and lack the expositional "sugar" of publications. The NoteCards database is an accurate, consistent presentation of the theory, but a private one that need not have expositional sugar. Metaphorically speaking, it represents the integral over time of the lab notes. All the contradictions, reversals, and dead ends are removed.

To see why this is important, consider an analogy. Suppose a computer scientist builds a program and a mathematician builds a proof. Both the program and the proof can be accurately represented in writing. However, the typical publication doesn't print the program or proof, but only the key ideas and a discussion. Nonetheless, constructing the program or proof is a methodological necessity because
allows one to clarify the ideas and make them rigorous. On a deeper level, it may be important to have a concrete embodiment (i.e., a written one) of the program or proof as an aid to thinking about it. Now for the analogy. A theorist builds a theory, and the publications discuss it, just as a computer scientist builds a program and the publications discuss it. But unlike programs or proofs, a theory, usually has no accurate, written representation. That is, until NoteCards and its ilk were developed. The NoteCards database is about as close as any written artifact can get to expressing a whole theory. If the analogy holds, then we can expect NoteCards to help theorists clarify their ideas and make them rigorous. Moreover, the NoteCards database should serve as a concrete embodiment of the theory. This last feature seems particularly important to me. Nowadays, I view my work as building a NoteCards database qua theory. To theorize without building a NoteCards database seems like programming without building a program. One can do it, but it's harder.

Because NoteCards databases are accurate representations of theories, they have excellent potential as vehicles for collaboration. Moreover, because the user interface lies somewhere between a blackboard and a text editor, NoteCards may augment or replace them as the customary focus of a collaborative theory development effort. It is easy to imagine two people in different cities both editing the same NoteCards screen while the talking over the phone.

Being halfway between lab notes and journal articles may also make NoteCards a unique aid to graduate-level teaching. A NoteCard database would allow young theorists to crawl around inside a classic theory, getting to understand it more deeply than they could from journal articles. Incidentally, this is one answer to what could happen to NoteCard databases after their active development ceases: They might rest in graduate schools, enshrined in computational display cases for students to dissect.

The last comment should be that NoteCards is only a beginning. One can imagine many facilities that could be added to it to make theory development even better. For instance, a truth maintenance system (e.g., Kleer in preparation; Doyle, 1979; McDermott, 1983) would make it easier to revise the theory. When a hypothesis changes from winning to losing, the TMS would automatically retract all the arguments that depend on it. That may, in turn, cause other hypotheses to lose their support and become losers. Currently, such propagation is done by hand. Adding a TMS to NoteCards is just one example of how automatic inferencing techniques could be imported from Artificial Intelligence. NoteCards is a first step on the path towards a theoretician's workbench that is a synergistic combination of both in and artificial intelligence.


References


Another exemplary notecard

This is a typical title

Here is some text. Normally it would be more meaningful than this. The usual formatting capabilities exist, including multiple fonts, horizontal and vertical spacing, etc.

The new feature is pointers, like these

<Remark> Another exemplary notecard

<Rebuttal> Homo sapiens Homo sapiens

Homo sapiens

There is evidence that dolphins are intelligent. They can learn to speak simple grammatical sentences (see ). Moreover, they can do it in about the same amount of time it would take an adult to learn to speak a similar fragment of a second language. They can use tools ( ). They can solve puzzles of

Figure 1

Examples of notecards
1. An issue: something that the theory must take a stand on
   A. Hypothesis 1
      1. Pro
         a. an argument in favor of the hypothesis 1
            i. an empirical fact used in the argument
            ii. another fact...
         b. another argument in favor of hypothesis 1
            i. an empirical fact...
      2. Con
         a. an argument against hypothesis 1
            i. an empirical fact used in the argument
            ii. another fact...
         b. another argument against hypothesis 1
         c. another...
      3. Moot
         a. an argument that bears on hypothesis 1, but is not decisive
         b. another such argument
   B. Hypothesis 2
      1. Pro
         a. an argument in favor of the hypothesis 2
         b. another argument in favor of the hypothesis 2
      2. Con
         a. an argument against hypothesis 2
         b. another...
      3. Moot
         a. an argument that bears on the hypothesis 2, but is not decisive
         b. another such argument

11. Another issue....

Figure 2
An argument tree, displayed as an outline.

There is one notecard for each issue, one for each hypothesis, one for each argument, and one for each empirical fact. The issue notecard points to the relevant hypothesis notecards (e.g., for the above tree, card 1 would point to cards A and B). Each hypothesis notecard points to the argument notecards that concern it. An argument notecard points to the facts that it references.
Matrix format for arguments

A statement of the issue goes here.

\[ <\text{Evidence}> \text{Fact 1} \]
\[ <\text{Evidence}> \text{Fact 2} \]
\[ <\text{Evidence}> \text{Fact 3} \]
\[ <\text{Evidence}> \text{Parsimony 1} \]
\[ + \quad \sim \quad 0 \quad \sim \quad <\text{Competitor}> \text{Hypothesis 1} \]
\[ + \quad + \quad + \quad \sim \quad <\text{Competitor}> \text{Hypothesis 2} \]
\[ + \quad + \quad + \quad + \quad <\text{Winner}> \text{Hypothesis 3} \]

Miscellaneous comments, if any, go here.
The above is a 4-by-3 matrix. The columns are labelled by pointers to pieces of evidence; the rows are labelled by pointers to hypotheses. The cells of the matrix contain pointers to arguments. If a hypothesis can explain a piece of evidence, the corresponding pointer is labelled "$+$". A "$\sim$" label means that the evidence contradicts the hypothesis. A "$0$" label means the evidence neither supports nor contradicts the hypothesis.

Figure 3

A Cartesian product notecard
Figure 4

A browser notecard

...
Personnel Analysis Division, AF/MPX
5C360, The Pentagon
Washington, DC 20330

Air Force Human Resources Lab
AFHRL/MPD
Brooks AFB, TX 73235

AFOSR,
Life Sciences Directorate
Bolling Air Force Base
Washington, DC 20332

Dr. Robert Ahlers
Code N711
Human Factors Laboratory
NAVTRAQUIPCEN
Orlando, FL 32813

Dr. Ed Aiken
Navy Personnel R&D Center
San Diego, CA 92152

Dr. Earl A. Alluvisi
HQ, AFHRL (AFSC)
Brooks AFB, TX 78235

Dr. John R. Anderson
Department of Psychology
Carnegie-Mellon University
Pittsburgh, PA 15213

Dr. Steve Andriole
Perceptronics, Inc.
21111 Erwin Street
Woodland Hills, CA 91367-3713

Technical Director, ARI
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Patricia Baggett
University of Colorado
Department of Psychology
Box 345
Boulder, CO 80309

Dr. Meryl S. Baker
Navy Personnel R&D Center
San Diego, CA 92152

Dr. Gautam Biswas
Department of Computer Science
University of South Carolina
Columbia, SC 29208

Dr. John Black
Yale University
Box 11A, Yale Station
New Haven, CT 06520

Arthur S. Blaiwes
Code N711
Naval Training Equipment Center
Orlando, FL 32813

Dr. Jeff Bonar
Learning R&D Center
University of Pittsburgh
Pittsburgh, PA 15260

Dr. Richard Braby
NTEC Code 10
Orlando, FL 32751

Dr. Robert Breaux
Code N-C95R
NAVTRAQUIPCEN
Orlando, FL 32813

Dr. Ann Ehrman
Center for the Study of Reading
University of Illinois
51 Gerty Drive
Champaign, IL 61820

Dr. John S. Brown
XEROX Palo Alto Research Center
3333 Coyote Road
Palo Alto, CA 94304

Dr. Bruce Buchanan
Computer Science Department
Stanford University
Stanford, CA 94305

Dr. Patricia A. Butler
NIE Mail Stop 1806
1200 13th St., NW
Washington, DC 20208
Dr. Robert Calfee  
School of Education  
Stanford University  
Stanford, CA 94305

Dr. Jaime Carbonell  
Carnegie-Mellon University  
Department of Psychology  
Pittsburgh, PA 15213

Dr. Susan Carey  
Harvard Graduate School of Education  
337 Gutman Library  
Appian Way  
Cambridge, MA 0138

Dr. Pat Carpenter  
Carnegie-Mellon University  
Department of Psychology  
Pittsburgh, PA 15213

Dr. Robert Carroll  
NAVOP 01B7  
Washington, DC 20370

Dr. Fred Chang  
Navy Personnel R&D Center  
Code 51  
San Diego, CA 92152

Dr. David Charney  
Department of Psychology  
Carnegie-Mellon University  
Schenley Park  
Pittsburgh, PA 15213

Dr. Eugene Charniak  
Brown University  
Computer Science Department  
Providence, RI 02912

Dr. Michelle Chi  
Learning R & D Center  
University of Pittsburgh  
3333 O'Hara Street  
Pittsburgh, PA 15213

Dr. Susan Chipman  
Code --2TP  
Office of Naval Research  
800 N. Quincy St.  
Arlington, VA 22217-5000

Mr. Raymond E. Christal  
AFHRL/MCE  
Brooks AFB, TX 73235

Dr. Yee-Yeen Chu  
Perceptronics, Inc.  
21111 Erwin Street  
Woodland Hills, CA 91373-3713

Dr. William Clancey  
Computer Science Department  
Stanford University  
Stanford, CA 94306

Scientific Advisor  
to the DCNO (MPT)  
Center for Naval Analysis  
2000 North Beauregard Street  
Alexandria, VA 22311

Chief of Naval Education and Training  
Liaison Office  
Air Force Human Resource Laboratory  
Operations Training Division  
Williams AFB, AZ 85224

Assistant Chief of Staff  
for Research, Development,  
Test, and Evaluation  
Naval Education and Training Command (N-5)  
NAS Pensacola, FL 32508

Dr. Allan M. Collins  
Bolt Beranek & Newman, Inc.  
50 Moulton Street  
Cambridge, MA 02138

Dr. Stanley Collyer  
Office of Naval Technology  
800 N. Quincy Street  
Arlington, VA 22217

CTB/McGraw-Hill Library  
2500 Gardner Road  
Monterey, CA 93940

CDR Mike Connan  
Office of Naval Research  
800 N. Quincy St.  
Code 270  
Arlington, VA 22217-5000
Bryan Dallman  
AFHRL/LRT  
Lowry AFB, CO 80230

Dr. Charles E. Davis  
Personnel and Training Research  
Office of Naval Research  
Code 442P7  
800 North Quincy Street  
Arlington, VA 22217-5000

Defense Technical  
Information Center  
Cameron Station, Bldg 5  
Alexandria, VA 22314  
Attn: TD  
(2 Copies)

Dr. Thomas M. Duffy  
Communications Design Center  
Carnegie-Mellon University  
Schenley Park  
Pittsburgh, PA 15213

Edward E. Eddowes  
CNATRA N301  
Naval Air Station  
Corpus Christi, TX 78419

Dr. John Ellis  
Navy Personnel R&D Center  
San Diego, CA 92252

Dr. Richard Elster  
Deputy Assistant Secretary  
of the Navy (Manpower)  
Washington, DC 20350

Dr. Susan Embretson  
University of Kansas  
Psychology Department  
Lawrence, KS 66045

Dr. Randy Engle  
Department of Psychology  
University of South Carolina  
Columbia, SC 29203

Dr. William Epstein  
University of Wisconsin  
W. J. Brogden Psychology Bldg.  
1323 W. Johnson Street  
Madison, WI 53706

ERIC Facility Acquisitions  
4833 Rugby Avenue  
Bethesda, MD 20814

Dr. K. Anders Ericsson  
University of Colorado  
Department of Psychology  
Boulder, CO 80309

Edward Esty  
Department of Education, CERI  
MS 40  
1200 19th St., NW  
Washington, DC 20008

Dr. Beatrice J. Farr  
Army Research Institute  
5001 Eisenhower Avenue  
Alexandria, VA 22333

Dr. Marshall J. Farr  
2520 North Vernon Street  
Arlington, VA 22207

Dr. Pat Federico  
Code 511  
NPRDC  
San Diego, CA 92152

Dr. Jerome K. Feldman  
University of Rochester  
Computer Science Department  
Rochester, NY 14627

Dr. Paul Feistovich  
Southern Illinois University  
School of Medicine  
Medical Education Department  
P.O. Box 3353  
Springfield, IL 62708

Mr. Wallace Farzeig  
Educational Technology  
Bolt Beranek & Newman  
10 Moulton St.  
Cambridge, MA 02238

Dr. Craig I. Fields  
ARPA  
1400 Wilson Blvd.  
Arlington, VA 22209
Dr. James McBride
Psychological Corporation
1250 West 6th Street
San Diego, CA 92101

dr. James McMichael
Navy Personnel R&D Center
San Diego, CA 92152

Dr. Barbara Means
Human Resources
Research Organization
1100 South Washington
Alexandria, VA 22314

Dr. Arthur Melmed
U.S. Department of Education
724 Brown
Washington, DC 20208

Dr. Al Meyrowitz
Office of Naval Research
800 N. Quincy
Arlington, VA 22217-5000

Dr. George A. Miller
Department of Psychology
Green Hall
Princeton University
Princeton, NJ 08540

Dr. Lance A. Miller
IBM Thomas J. Watson
Research Center
P.O. Box 218
Yorktown Heights, NY 10598

Dr. Andrew R. Molnar
Scientific and Engineering Personnel and Education
National Science Foundation
Washington, DC 20550

Dr. William Montague
NPRDC Code 13
San Diego, CA 92152

Dr. Allen Munro
Behavioral Technology Laboratories - USC
1845 S. Elena Ave., 4th Floor
Redondo Beach, CA 90277

Spec. Asst. for Research, Experimental & Academic Programs,
NTTC (Code 016)
NAS Memphis (75)
Millington, TN 38054

Dr. Richard E. Nisbett
University of Michigan
Institute for Social Research
Room 5261
Ann Arbor, MI 48109

Dr. Donald A. Norman
Institute for Cognitive Science
University of California
La Jolla, CA 92093

Director, Training Laboratory,
NPRDC (Code 05)
San Diego, CA 92152

Director, Manpower and Personnel Laboratory,
NPRDC (Code 06)
San Diego, CA 92152

Director, Human Factors & Organizational Systems Lab,
NPRDC (Code 07)
San Diego, CA 92152

Fleet Support Office,
NPRDC (Code 301)
San Diego, CA 92152

Library, NPRDC
Code P201L
San Diego, CA 92152

Commanding Officer,
Naval Research Laboratory
Code 2627
Washington, DC 20390
Dr. Claude Janvier
Directeur, CIRADE
Universite' du Quebec a Montreal
Montreal, Quebec H3C 3P8
CANADA

Margaret Jerome
c/o Dr. Peter Chandler
63, The Drive
Hove
Sussex
UNITED KINGDOM

Dr. Joseph E. Johnson
Assistant Dean for
Graduate Studies
College of Science and Mathematics
University of South Carolina
Columbia, SC 29208

Dr. Douglas H. Jones
Advanced Statistical
Technologies Corporation
10 Trafalgar Court
Lawrenceville, NJ 08648

Dr. Marcel Just
Carnegie-Mellon University
Department of Psychology
Schenley Park
Pittsburgh, PA 15213

Dr. Milton S. Katz
Army Research Institute
111 Eisenhower Avenue
Alexandria, VA 22333

Dr. Scott Kelso
Haskins Laboratories,
375 Crown Street
New Haven, CT 06510

Dr. Norman J. Kerr
Chief of Naval Education
and Training
Code ONR
Naval Air Station
Pensacola, FL 32508

Dr. Dennis Kizler
University of California
Department of Information
and Computer Science
Irvine, CA 92717

Dr. David Kieras
University of Michigan
Technical Communication
College of Engineering
1221 E. Engineering Building
Ann Arbor, MI 48109

Dr. Peter Kimble
Training Analysis
& Evaluation Group
Department of the Navy
Orlando, FL 32813

Dr. David Kiernan
Carnegie-Mellon University
Department of Psychology
Schenley Park
Pittsburgh, PA 15213

Dr. Mazine Knerr
Program Manager
Training Research Division
HumRRO
1100 S. Kentington
Alexandria, VA 22314

Dr. Janet L. Kolodner
Georgia Institute of Technology
School of Information
& Computer Science
Atlanta, GA 30332

Dr. Kenneth Kolovsky
Department of Psychology
Community College of
Allegheny County
800 Allegheny Avenue
Pittsburgh, PA 15203

Dr. Benjamin Kupers
MIT Laboratory for Computer Science
545 Technology Square
Cambridge, MA 02139

Dr. Patrick Kyllonen
AFHRL/MOE
Brooks AFB, TX 78235
Dr. Michael J. Samet  
PerceptroniCS, Inc  
6271 Variel Avenue  
Woodland Hills, CA 91364

Dr. Robert Sasmor  
Army Research Institute  
5001 Eisenhower Avenue  
Alexandria, VA 22333

Dr. Roger Schank  
Yale University  
Computer Science Department  
P.O. Box 2158  
New Haven, CT 06520

Dr. Alan H. Schoenfeld  
University of California  
Department of Education  
Berkeley, CA 94720

Dr. Janet Schofield  
Learning R&D Center  
University of Pittsburgh  
Pittsburgh, PA 15260

Dr. Judith Segal  
Room 819F  
NIE  
1200 19th Street N.W.  
Washington, DC 20208

Dr. Ramsay W. Selden  
NIE  
Mail Stop 1241  
1200 19th St., NW  
Washington, DC 20208

Dr. Michael G. Shafto  
ONR Code 442PT  
800 N. Quincy Street  
Arlington, VA 22217-5000

Dr. Sylvia A. S. Shafto  
National Institute of Education  
1200 19th Street  
Mail Stop 1806  
Washington, DC 20208

Dr. T. B. Sheridan  
Dept. of Mechanical Engineering  
MIT  
Cambridge, MA 02139

Dr. Ted Shortliffe  
Computer Science Department  
Stanford University  
Stanford, CA 94305

Dr. Lee Shulman  
Stanford University  
1040 Cathcart Way  
Stanford, CA 94305

Dr. Miriam Shustack  
Code 51  
Navy Personnel R & D Center  
San Diego, CA 92152

Dr. Robert S. Siegler  
Carnegie-Mellon University  
Department of Psychology  
Schenley Park  
Pittsburgh, PA 15213

Dr. Herbert A. Simon  
Department of Psychology  
Carnegie-Mellon University  
Schenley Park  
Pittsburgh, PA 15213

Dr. Zita Simutis  
Instructional Technology  
Systems Area  
ARI  
5001 Eisenhower Avenue  
Alexandria, VA 22333

Dr. H. Wallace Sinaiko  
Manpower Research  
and Advisory Services  
Smithsonian Institution  
801 North Pitt Street  
Alexandria, VA 22314

Dr. Derek Sizemore  
Stanford University  
School of Education  
Stanford, CA 94305

Dr. Edward E. Smith  
Bolt Beranek & Newman, Inc.  
50 Moulton Street  
Cambridge, MA 02138
Dr. Joseph L. Young
Memory & Cognitive Processes
National Science Foundation
Washington, DC 20550

Dr. Steven Zornetzer
Office of Naval Research
Code 440
800 N. Quincy St.
Arlington, VA 22217-5000

Dr. Michael J. Zyda
Naval Postgraduate School
Code 52CK
Monterey, CA 93943
END

DTIC

8-86