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Intelligent Embedded Instruction for CAD Systems

Followup Studies of Embedded Instruction for CAD Systems

by
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The U.S. Army Construction Engineering Research Laboratory (USACERL) previously developed and tested an online embedded instruction system for teaching computer-aided design (CAD) to architects, engineers, and other design professionals. That study's results showed that online CAD instruction should provide more effective help for users having different learning styles and levels of experience with such systems. In addition, the study raised questions about the type of CAD concepts needed by designers and how to provide them in an online instruction program.

This research used interviews with test subjects from the previous study to identify ways of making online CAD instruction more efficient and effective. The interviews showed that subjects displayed various levels of conceptual understanding of the system, differences in learning style, and individuality of work methods. This study recommends ways to enhance conceptual understanding and accommodate individual variations in learning style, online CAD experience, and work methods. (KR) ←

The research will contribute to updated versions of the Teaching Assistant series, which has been transferred to industry through a Cooperative Research and Development Agreement (CRDA) in accordance with the Federal Technology Transfer Act of 1986.

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FOREWORD

This research was conducted for the Directorate of Military Programs, Headquarters, U.S. Army Corps of Engineers (HQUSACE), under Project 4A162784AT41, "Military Facilities Engineering Technology"; Work Unit SA-A99, "Intelligent Embedded Instruction for CAD Systems." The HQUSACE Technical Monitor was Mr. Don Dressler, CEMP-ED.

The work was performed by the Facility Systems Division (FS) U.S. Army Construction Engineering Research Laboratory (USACERL). Dr. Michael O'Connor is Chief of USACERL-FS.

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LTC E.J. Grabert, Jr. is Commander of USACERL and Dr. L.R. Shaffer is Director.

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1 INTRODUCTION

Background

USACERL research in computer-based instruction for professional designers began in the fall of 1985. The objective was to develop new approaches to learning complex computer-aided design (CAD) systems in order to solve the problem of technology transfer to design professionals in the Corps and in the private sector. Computer-based training offered the possibility of low-cost support that could facilitate technology transfer and increase the effective use of CAD, and USACERL developed and tested an embedded instruction program for teaching CAD.

The report on this research[1] concluded that architects and engineers profit from online instruction embedded in the CAD system they are learning. Although these users varied widely in the time spent studying lessons and in the learning strategies they employed, questionnaire responses showed a preference for this type of instruction. In addition, the professionals who participated in the study demonstrated that they understood their own learning needs well and that they could be given a high degree of learner control of the computer-based instructional program.

Even so, the study raised questions about the type of CAD concepts needed by designers and the best way to provide them in an instructional program. For example, the final drawing test measured subjects' use of the CAD system as a drafting tool, but did not reveal much about the conceptual knowledge involved in successfully executing the system for design purposes. In addition, the attitude scale given in the last test indicated wide differences in modes of learning. Thus, the need to make the instruction more flexible to accommodate different learning styles suggested system approaches that needed further investigation.

Objective

The objective of this research was to identify ways of making online embedded instruction systems for teaching CAD more efficient and effective. This work would thereby contribute to the instructional model of computer-based training that had already been developed. In addition, if gaining a conceptual understanding of CAD could be made more efficient for the learner, further savings in cost and time could be realized.

Approach

The investigators interviewed architects and engineers who had been test subjects for the previous study.[2] The subjects were selected by the project coordinators of the three official U.S. Army Corps of Engineers (USACE) test sites: Huntsville Division, New England Division, and Baltimore District. Each project coordinator was asked to select subjects from a variety of experience levels and professional backgrounds who were both verbally skilled and interested in being interviewed. (A few users volunteered who had not participated in the original study. Their help was welcomed because of the information provided about learning styles, concept understanding, etc.)

[1] D. S. Shaw, L. M. Golish, and R. L. Johnson, *Intelligent Embedded Instruction for Computer-Aided (CAD) Systems*, Technical Report P-89/03/ADA201811 (U.S. Army Construction Engineering Research Laboratory, October 1988).

[2] D. S. Shaw, et al.

The interviews were structured to discover the most powerful feature of CAD as perceived by the subject, the subject's learning style, and the particular CAD concepts he or she was aware of. Special questioning was intended to reveal their understanding of the mathematical data base, algorithms or rules involved in the commands, and complex entity libraries. The rationale behind the selection of these concepts is provided in Chapter 2.

The interviews were conducted at the subject's worksite over a period of several months. In many cases, the subjects were able to illustrate their comments on their computers, although some preferred to draw on paper or just talk about their experiences. Each interview is briefly reported in Chapter 3. Regarding subjects involved in the previous study, test scores and attitude measures were available, and these factors were considered in reaching conclusions and drafting recommendations. In addition, an attempt was made to correlate the concepts learned with other factors in the test subject's background.

Mode of Technology Transfer

The software for AutoCAD training, "Teaching Assistant for AutoCAD," was transferred to a private company through a Cooperative Research and Development Agreement (CRDA) under the Federal Technology Transfer Act of 1986, Public Law No. 99-502. This agreement provides a mechanism for technology transfer to the architect/engineer (A/E) community as well as to secondary and higher education. This study will contribute to updating both the AutoCAD version and the new Teaching Assistant for MicroStation. The MicroStation training is of particular interest to USACE since it is the PC-based version of the Intergraph software, the system selected for CAD use Corps-wide. Demonstrations under the Corps of Engineers National Automation Team (CENAT) Technology Transfer Test Bed, as well as the Facilities Engineering Applications Program (FEAP), have been requested for that software.

2 PROCEDURE

The procedure consisted of asking questions that encouraged the interviewees to communicate their learning style and their understanding both of CAD concepts and of the main value of CAD. The researchers thought learning style might influence user success in computer-based instruction. The question of a user's understanding of graphic concepts and its relationship to computer-aided design has been discussed in recent publications and conferences.

The previous USACERL study[3] included a questionnaire that measured attitudes toward computer-aided design. Architects and design engineers unanimously agreed with the statement "Computers are helpful in the design process." However, there was wide disagreement about how that help takes place. The controversy hinges on the relationship of computer graphic concepts and design concepts. On the one hand, the computer may be considered a simple tool, like a pencil, which the designer employs to communicate a design. On the other hand, the computer itself can be considered the ultimate designer, making decisions according to rules having little apparent human intervention. To design within *any* definition of CAD, however, certain concepts must be understood. If the program is used mainly as a drawing tool, the user should understand the geometric principles of precision drafting. But if the program is viewed as a means of varying symbols in design, the user should understand the concepts of complex entities, and other views, similarly, require other conceptual understandings.

The methods of teaching basic concepts necessary for successful computer aided design have also been widely discussed. One viewpoint is that the power of the designer is extended by learning computer graphic concepts through programming. It is commonly believed that architects must understand programming to use computers in design, and programming is a curriculum requirement in many architecture schools. A recent graphics programming textbook[4] says the computer program is to drawing as a score is to music. Another author asks if innovation in design comes about as a function of "programming the computer to generate forms and transformations heretofore too complex to occur to any but, perhaps, the most creative designers."[5]

This study was concerned with discovering whether the test subject (most had no experience in programming) had learned the type of concepts taught in programming classes. One objective of programming courses is the formulation of rules, or algorithms, by which the computer is able to construct entities, such as lines and circles. These entities are geometric and involve calculation of angles and distances. Some of the calculations involved are extremely difficult to accomplish without using a computer; for example, constructing a circle through three points or drawing a reflected or mirrored image. Another concept taught in programming is the complex entity. Using computerized procedures, programmers link several objects together so they can be manipulated as a unit. Students learn how to establish these links and the rules by which the complete set can be transformed. Both simple and complex entities are programmed into repeated patterns with changes imposed by algorithmic rules. All these calculations and rules operate upon numeric quantities, and students are expected to understand the mathematical and algorithmic concepts involved in computer graphic programs.

The questioning sessions were designed to allow the subjects to respond freely using their own terms. The question, "What do you think the greatest power of the CAD system is?" was intended to bring out their understanding of computerized graphic concepts, but careful questioning about the concepts themselves was usually necessary. Answers to questions such as, "Why do you suppose I find such large errors in the location of mirrored objects when people use the mirror command?" would reflect the

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[3] D. S. Shaw, et al.

[4] W. J. Mitchell, R. S. Liggett, and T. Kvan, *The Art of Computer Graphics Programming* (Van Nostrand Reinhold Company, Inc., 1987.

[5] C. Yessios, "A Fractal Studio," In B. Novitski, Ed. *Integrating Computers into the Architectural Curriculum*, ACADIA Workshop '87 Proceedings (University of Oregon, October 1987), pp 169-181.

student's knowledge about the algorithm that would produce a mirror copy and about the necessity for precision placement of the mirror line. A question about the use of complex entities in drawings would either draw a blank or evoke a specific application of which the subject was aware. These applications often provided insight into the user's particular orientation to the CAD system. Those who became enthusiastic about the power of iteration or variation had knowledge of concepts basic to design. Often editing and presentation purposes, such as file transfer and output, required conceptual understanding of algorithms and mathematics beyond the level of procedural operation of the CAD system.

Learning style was also a focus of the questioning. The subjects were asked whether they followed the linear sequence in the lessons, and their answers often revealed their inclination to experiment, jump around in the lesson, and follow an individualized study plan. They were also asked whether they used reference books and the online help provided by AutoCAD. Learning styles were categorized as follows: "structured" learners prefer a closely monitored situation with clear-cut objectives and feedback, "guided-discovery" learners tend to follow the structure of online lessons but experiment when they have a question, and "discovery" learners tend to disregard the lesson structure and work according to their own plan, using menus and testing ideas of their own creation.

Subjects often provided their own ideas and demonstrated their skills in using the CAD program to accomplish their particular goals. Usually this type of approach led to about 20 minutes of conversation, which provided the framework for the following reports.

3 CASE STUDIES

The interviews which resulted in the case studies reported here were conducted between July and December 1988. The test sites from which the subjects were selected were Huntsville Division, New England Division, and Baltimore District offices of the U.S. Army Corps of Engineers. The subjects' initials have been changed since their comments were intended to be kept confidential. Test scores and times reported here were recorded during the previous study.[6] The attitude score was high if the attitude was positive toward computer-based instruction and low if the attitude was negative. (Scores and ages are not included for volunteer participants, who had not participated in the previous study.)

AJ

This subject was a 46-year-old male architect. He spent a little less time on the lessons than most and scored well below the average of the total test group. He did not take the attitude test. He seemed frustrated by the lessons and was unaware of the data base or the algorithms mentioned in our interview conversation. He reported trying to use online help, but had trouble getting it. He was eager to recommend that the researcher read a book about computer-aided design which interested him. He has not used CAD for design and did not expect to, although he found it an interesting subject. His learning style was structured, and he supposed that editing drawings and using repeated objects might be strengths of CAD.

BK

BK was a 43-year-old male engineer. He had a very low drawing score, but had one of the most positive attitude scores on computer-based training. He was a guided discovery learner and thought the lessons covered AutoCAD very well. He also reported attending a 3-day course on AutoCAD taught by a vendor. He had a little experience in another CAD system and was very enthusiastic about using the computer. He wanted a PC on every desk. One of his concerns was learning the motor skills to operate the program efficiently. He was impressed by draftsmen who could locate commands on the digitizer without looking at it. His conceptual level was not very deep and centered mainly on the machine's memory capacity and the speed the CAD system could add to drafting.

CL

This young female engineer spent almost twice the average time on the lessons. She had an average score on the test and a below average attitude score toward the lessons. She could be classified as a low-level guided-discovery learner, keeping her own set of notes, looking at documentation, and following the lesson closely. She thought editing and calculating were the CAD system's powers and seemed to have little understanding of the nongraphic data base concept.

DM

This 39-year-old male engineer had no previous CAD experience. He was not able to verbalize concepts himself, but seemed to have an understanding of the mathematical data base and the algorithmic nature of the program. The most interesting concept that he seemed to embrace was "the integration of work possible on a CAD system." He had experimented with ideas that might work for system operating procedures, even though he had not investigated systems at other sites. He spent less-than-average time on the lessons, scored well on the test, and liked the lessons. He was a guided-discovery learner.

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[6] D. S. Shaw, et al.

EN

A 39-year-old male engineer in a managerial position, EN was a heavy user and advocate of CAD. He used it to make final corrections on the work done by draftsmen before submission for review, and he thought he had perfected his system so it was efficient and elegant. He skillfully used complex entities and nongraphic attributes. He reported about average time on the lessons, but did say he worked extra after work to develop his special skills. His attitude toward the lessons was more positive than the average. He seemed to be a discovery learner, concentrating on the features he was most interested in and skipping other information. He had used a book to help him go deeper into the subject of attributes and blocks. His conceptual understanding was limited to areas of his interest, and he scored lower than average on his final drawing.

FO

FO was a guided-discovery learner. He reported that he read each screen and "played around." CAD was new to him but he was learning fast. He seemed unsure of himself when discussing concepts, but he was excited about copying entities to avoid duplication. Using the CAD system for other functions, such as art work, interested him. He was an engineer, 23 years old, and had not been trained in CAD at college. He stressed that his work load did not allow much time for CAD and that the reference manual helped him save time. He spent average time on the lessons and scored well on the test.

GP

GP was a male architect, 42 years old, experienced in other CAD systems, who had attended outside training courses. He scored slightly below average on the test and reported above average hours on the lessons. He experimented somewhat, but tended to do just what the program asked for. He liked to have a reference book available and seemed fairly structured in his study habits, reporting a low attitude score toward the computer-based training. Editing and scaling complex entities were his choices for power of the system, and he also reported that CAD helped him organize his work. He had a very good grasp of complex entities, developing symbol libraries, and precision drafting. After watching experts in his training class, his concern was for developing a high level of motor skill in program operation.

HQ

HQ was a female technician, 37 years old, who used the guided discovery method to learn and spent over five times the average on the lessons. She scored just below average on the test and thought that editing and scaling were the strengths of the system. She understood the concept of complex entities and symbol libraries. She did not use a book, but tried to work out solutions on her own. She would like to use CAD for all her work, but could not get a project that required it.

IR

This technician, male and 34 years old, thought CAD was wonderful. He had started by going screen by screen, but began to experiment more as he got more comfortable. He found the lessons easy and liked this guided-discovery way of learning. His attitude toward the lessons was strongly positive. He said he put in a lot of time, and he developed an understanding of complex entities. He also seemed to have some understanding of algorithms, but he needed to think about it more. He wanted a book at first, but later did not use it and did not use online help.

JS

JS was structured in his learning style and seemed to be more interested in evaluating the system than learning it. He did not like the system, and he thought that another one was better. He did not find any strengths in the systems, although he discovered differences between it and his first system. His attitude toward the lessons was negative. His test score was high, and he seemed to understand concepts such as the algorithmic base of the command structure. JS was a male engineer, 27 years old, who spent about average time on the lessons.

KT

KT also had experience on another system. He was a 26 year-old engineer who spent less than half the average time on the lessons. He said he "breezed through" the lessons and might use the system if he ever got adequate training. He preferred structured training, such as that provided by the vendor. He thought CAD was too expensive and was being pushed too much by the A/E community. He thought it was useful for repetitive jobs, and he had some understanding of editing concepts. He thought that AutoCAD was hard to use, and he scored poorly on the test.

LU

LU was an architect, 42 years old, who had extensive experience in another system. He used the discovery method, trying to make this system do what the other one did. He explored the interface between this and the other system and tried file transfer. He found the lessons boring and was very interested in catching errors in the AutoCAD system. He often had ideas about how the system should be designed, but he could not find any software that completely satisfied him. He had well-developed concepts of complex entities and the data base, and he liked to develop his own shortcuts. His drawing score was one of the highest, and he rated computer-based training as strongly positive. He reported that he did not like books.

MV

An interesting statement made by MV was that she was learning to "think like a computer." She had taken two vendor-taught CAD courses in another CAD system since the formal test, and she had developed a good understanding of the mathematical data base, complex entities, and command algorithms. She was a 28-year-old architect, and she was doing design projects with CAD at the time of the interviews. Her learning style could be described as guided-discovery, employing online help and exploring new ideas. She spent extra time trying to develop approaches to solving design problems when she encountered difficulties with the software system. She said her knowledge of computer thinking came during the two recent courses when she was able "to put it all together."

NW

NW, a 36-year-old engineer, was experienced with CAD systems. He seemed to have a good understanding of computer concepts including rules, data bases, and mathematical transformations. He had some background in computer programming. His learning style was structured, and he reported some problems learning the procedures. He said he could edit faster on paper than with CAD. His test score was high, and his attitude toward computer-based training was more positive than most.

OX

A 41-year-old technician, OX had used another CAD system extensively. He used guided-discovery learning, but needed a book to get started on the PC. Once started, he used online help and experimented with the program. OX understood the concepts of complex entities and used them in his work. He understood data base changes, particularly with regard to editing changes, and thought the editing capabilities on the personal computer (PC) were better than expected. He had worked out a unique method for cleaning up drawings, particularly for line extensions and double lines. It was interesting that he was concerned about the size of the drawing file and tried to find ways to cut it down. This was important to him not only to increase the speed of work but also for file transfer from system to system.

PZ

PZ, 32 years old, was new to the PC but not to CAD. His experience as a draftsman on a mainframe system made the PC seem difficult. However, the PC system was not hard for him to learn, and he followed the lessons with ease. He tended to be structured in his learning; he did not explore extensively. He had some understanding of the mathematical data base, particularly for such editing tasks as correcting multiple lines in a drawing.

QA

QA, a 21-year-old technician, worked quickly through the lessons with only some experimentation; his learning style was something between structured and guided-discovery. His attitude score was strongly positive toward the lessons. He used online help and found its speed the main power of the computer. He was aware of the symbol library and the mathematical data base, but had not explored them very deeply. He had a little experience with another CAD system, and he used a book for additional reference.

RB

RB used the manual for assistance and to speed up his learning. He liked the lessons, but the pace was not fast enough for him. He had used three CAD systems extensively and was pleased to find that this one would do just about what he wanted. He was interested in tailoring the menus to his own style and asked for programming help. In the interview he showed his tricks for fast presentation displays. He was a guided-discovery learner at first, but tended to get away from the lessons and sped himself up using the book. His interest in editing and complex entities showed good understanding of CAD concepts. RB was a 33-year-old technician.

SC

A guided-discovery learner, SC was a 43-year-old architect. She was impressed by the quality of the printed drawings and liked to try to improve the quality of her output. She also reported liking her word-processing program better since she had learned the CAD system. She was not particularly concerned with CAD concepts but thought they sounded interesting. She followed the lessons for a time and then tried her own ideas.

TD

TD was a 24-year-old engineer who had used other CAD systems. She "knew what to expect" and took a structured approach to learning the system. She liked CAD because it was easy to modify, and she was not concerned with the concepts. She didn't use the book or the online help, but just worked through the screens. Her attitude toward the lessons was neutral.

UE

UE spent almost twice as long as average on the lessons. A 34-year-old draftsman, he had a structured learning style and an average attitude score toward the lessons. He worked through the lessons in order with little review time. He was interested in the neat output from the program, particularly dimensioning and changing elements. The CAD system was new to him, and he looked forward to using it for drafting. During the lessons he started using the system for a project. His score was about average on the final drawing, even though his understanding of the conceptual base was quite low. He pointed out that he learned more from the final castle drawing than he had from the lessons.

VF

A 40-year-old architect, VF was inexperienced with CAD systems. He followed the lessons, experimenting a little, and was a guided-discovery learner. His attitude toward the lessons was more negative than most, and he spent over twice as long as the average student and scored very high on the test drawing. His understanding of complex entities was not very well developed. He was interested in using numeric input for accuracy and thought that accurate drawings were the main objective of CAD. He didn't find enough information in the lessons or in the reference books. He did not like to use books or online help, but learned slowly from trying to accomplish drawings.

WG

WG, a technician, did not complete the lessons, but wanted to talk about learning CAD. He taught himself about 12 commands in the CAD system and felt that it was difficult at first. He was too rushed for time to explore the commands; he practiced them only when they were needed. He was involved in production drafting and felt that he could not take time for training.

XH

This architect knew five CAD systems and had picked up the new system without the help of training. He thought the greatest potential of the CAD system was in its manipulation of complex entities. He sketched on paper as he indicated scaling, angle, and detail changes. His interest was in shape and form variation in building design. He stressed he was not a programmer, and he thought CAD was a wonderful tool for the designer even if he could not program. He mentioned that he might have to learn programming to do some of the things he thought of. He was a discovery learner, but he felt it was a good idea to have some plan to learning. He did not like to learn from a book, but from the system itself.

4 ANALYSIS OF INTERVIEW RESULTS

Concept Understanding

The group displaying the greatest understanding of the CAD system was examined. Of the seven interviewees who seemed to possess a high degree of conceptual understanding of computer graphics, four were architects. They all had extensive experience with other CAD systems and were using the computer for what they described as design. They were interested in architectural applications packages and could be called enthusiastic users. Three were concerned with the software's limitations in solving some of their design problems. Two seemed to be discovery learners. The engineer with a well-developed knowledge of CAD concepts was also a computer programmer with a structured learning style. The technicians with the highest conceptual understanding had previous experience on mainframe systems, were guided-discovery learners, and were involved in daily work with CAD. The common factors were (1) all of them spent much of their time on the computer as a requirement of their jobs, and (2) all seven members of this group knew another CAD system well, as would be expected from our previous study.[7]

Nonproductive attitudes, especially bias, were associated with a lower degree of concept learning. Two subjects who had previous experience with other CAD systems, but did not possess as high a degree of conceptual understanding of the system, were both structured learners who were not interested in this CAD system. One of them did not work on computers much, and the other worked primarily on a mainframe system for which he had received vendor-supplied training. Neither seemed anxious to work out problems or develop personal ways of using this system.

There was evidence that group dynamics influenced the attitudes of certain individuals. Several test subjects who worked on a mainframe at one site noticed speed reduction in editing and initial loading of the program which tended to bias them against the slower PC system. In addition, several colleagues at one test site were concerned with developing "motor" skills associated with using the system, although that was not mentioned anywhere else. This concern was judged to be distracting by others. On the other hand, the enthusiasm of a group of experienced users seemed to pervade the entire environment at another site. Thus group dynamics were found to lead to positive as well as negative effects.

Learning Style

Learning style was another factor considered. The lessons seemed to be more effective for those who learned by the discovery or guided-discovery method. Of the CAD beginners who had developed some expertise in the concepts under investigation, all were classified as guided-discovery or discovery learners, while the group with the least conceptual understanding was for the most part made up of structured learners. Subjects who did not explore and discover either did not find information beyond the content of the lessons or, perhaps, did not absorb the lesson content that was provided. In any case, those unconcerned or unaware of the graphics concepts in CAD did not score well on the test drawing. Those subjects were more impressed with output quality and modification of existing drawings than with the design potential of the system. Learning style did make a difference in learning graphic concepts.

In several cases, learning style seemed to change as the student became more familiar with the system. Typically students would be quite structured when they began the lessons, but would move toward discovery learning as they became more familiar with the system and the method of work. This occurrence may reflect some of the findings that occur in educational simulations.[8] It has been found that a high degree of fidelity between the instructional environment and the situation in which the learning is

[7] D. S. Shaw, et al.

[8] S. M. Alesso, "Fidelity in the Design of Instructional Simulations," *Journal of Computer-Based Instruction*, Vol 15, No. 2 (Spring 1988), pp 40-47.

to be used is more successful with sophisticated students than with novices. For example, advanced students in pilot's training would be expected to profit from actual experience in a plane, but the beginner would be too tense to learn from it. Not even an extremely realistic flight simulator would be recommended for complete beginners. Embedded training in a CAD system, therefore, in which all the power and complications of the system are available to the student, may be very frightening for the beginner. But as the student gains confidence, he or she is able to take advantage of the opportunity to test ideas about how the system works. However, changes in learning style do not occur at the same rate for different users, and they may not happen at all.

Individualized Applications

One of the most impressive considerations was the individuality developed by each CAD user who became enthusiastic about the system. A wide range of unique applications were developed by the interviewees. They created special ways to accomplish particular job tasks, from quick presentations to last minute editing tricks. In each case, these were closely related to the work done by the individual involved. It seemed that each person saw the CAD system in light of his or her own special interest, whether it was graphic art or variations in building design. Those concerned with file transfer noticed "clean" data bases and the size of the file, and those concerned with accuracy learned the information about numeric input. Users might not even notice features they did not use in their work. Thus, as in other adult education environments, subjects seemed to be able to take their own "slice of the pie" and leave the rest until later. The statistical analysis in the previous study did not capture this element of individual variation.

The complexity of the individual applications worked out by test subjects was beyond the level of the introductory training they had received. This suggested that the instruction they received did not oversimplify the power of the system. Initial oversimplification of complex subject domains has been shown to have a handicapping effect on advanced concept development.[9] In general, those who attempted to solve problems and make the system fit into their work learned more and reported they were continuing to learn independently. In many cases, the software was not easy to adapt to their individual needs. This was clearly a case of the students setting their own course objectives and measuring their own progress. Several interviewees pointed out that they learned from their projects and reviewed parts of the lessons as they encountered practical applications in their work.

Job Relatedness of Instruction

The availability of job-related work that required CAD influenced learning. If the interviewees were able to do projects on the computer and use it as an extension of their own abilities, understanding grew. Many had requested and obtained projects that would permit them to use the CAD system. (At one site, they were having difficulty obtaining the hardware and software for such project development.) However, subjects whose job did not require use of the CAD system did not reach as high a level of conceptual understanding as the others.

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[9] R. J. Spiro, M. J. Jacobson, and J. Jehng, "Hypertext and Cognitive Flexibility: Theory and Technology for Learning in Complex Knowledge Domain," *Proceedings of the 30th International ACDIS Conference* (November 1988).

5 CONCLUSIONS AND RECOMMENDATIONS

1. Previous use of CAD strongly predicted a high level of understanding of the new system.

2. Learning style influenced the ability to learn from computer-based embedded instruction.

3. Individuality in the preferences and styles of work within the subject group was considerable.

4. Learning continued after the instruction period if the student was actively using the CAD system.

5. Concept development occurred through experimentation and testing ideas in a realistic environment.

Since this research aimed at investigating methods for improving ways of providing knowledge to professional designers, much more than procedural instruction for CAD software must be considered. (Vendors and training courses usually concentrate on training for execution of the drafting commands of the system.) Understanding the graphics concepts of the system and assisting in design decisions are objectives necessary for the education of designers, and the recommendations are based on these objectives as well as the research findings.

It is advantageous for designers to be familiar with several CAD environments. Because the design process involves problem solving, the system must be compatible with the type of representation the designer wishes to establish. Many options in software and instructional choices must be available to architects and engineers because their enthusiastic interest in using the system appears to be a necessary prerequisite for learning to use it. Bias, either from preference for the features of another system or from the difficulty of achieving a desired representation, kills interest, but "learning can be defined as the process of remembering what you are interested in."[10] Moreover, the present research shows that conceptual knowledge of a system increases with experience in additional systems.

Future computer-based CAD training for designers should include continuing and extending the use of embedded training, particularly for advanced users. Only within the system can users experiment and test their hypotheses. Further, an attempt must be made to embed design decision assistance, as well as instruction for the use of the system, so the user can seek help if and when it is needed. It has been noted that "users of information are more likely to value information which they themselves seek out, as opposed to information which is merely presented to them without solicitation."[11] Thus help should be available to the designer directly from the design file without leaving the current work, and the assistance should be viewed and manipulated very rapidly without undue waiting and loading periods. Current developments in multitasking and expert systems may provide a suitable vehicle for such a system.

For example, a fire code expert system could be useful to an architect. If the designer wished to find out whether a given door satisfied local fire regulations, he or she might select it in a drawing and ask the system. The expert system would apply rules to locate rooms, hallways, door swing, size, and material. The fire code data base would then allow the system to verify that it would comply or in what way it needed modification. Other applications might include calculating building placement for maximum passive solar optimization or handicap access to a facility. Since Corps users are sophisticated, it is recommended that their instructional systems be largely user controlled because such users can reliably select what they need.

[10] R. S. Wurman, *Information Anxiety* (Doubleday, 1989), p 138.

[11] A. S. Knicely, "A Study of the Use of Social Information in Decision Making," *Dissertation Abstracts International*, Vol 47, Section 9 (1969), p 3994.

It is also recommended that users be able to use systems in many ways, according to individual preference. Ideally, each person should be able to find help to suit his or her learning style. There might be structured lessons, closely monitored by the computer, as well as discovery challenges to stimulate experimentation. The student should be able to select a comfortable style of study with different paths available. Learning style does seem to be subject to change, and future computer-based training should attempt to shift the learner to the discovery orientation. This type of aim may be accomplished by using a hypertext approach in the instructional system. Users could request the type of assistance they desire, with the option to seek more help at any time.

The final recommendation is that each designer be provided with his or her own workstation with appropriate design software. One of the factors which influenced the degree of learning of the CAD system was the time users were able to spend on a computer. For design work to proceed, architects and engineers must be able to invest time and have the convenience of a private computer. In addition, it should be possible to network personal computers to transfer drawings and reach data bases. Thus the designer will be able to pursue his or her individual support needs for productive use of CAD.

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