CASE STUDIES IN ARCHITECTURAL CADD EDUCATION

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Abstract

Stages in the formation of concepts necessary for mastery can be observed in cognitive development in many different areas of study. These stages seem to follow a particular hierarchy common to most learners. Distinct levels can be recognized by patterns of procedural errors. The remediation of errors can then take the form of building a conceptual framework rather than training in procedural patterns. This has been found to be highly efficient for learners at all stages since it can be aimed at the underlying problem area and not at isolated errors which may change frequently. It was felt that concept development of architects learning to use computer-aided drawing programs would show such levels.

Preliminary studies made at the U.S. Army Construction Engineering Research Laboratory upon selected subjects using computer-aided lessons in AutoCAD as a basis for observations reveal several categories of errors in using computer-aided design. These case studies show that the design process can be enhanced by automated drawing and design tools if the conceptual relationships are established as a part of the learning environment. Even more important, the observations show that architects have particular characteristics which differ from engineers and other CAD users. These differences require that education and software be tailored to their needs.

Introduction

The problem of persuading architects to use automated drawing programs has been recognized both in the U.S. Army Corps of Engineers and in the private sector. Many architects express reluctance to use computers, stating that machines limit their creativity or de-humanise the design process. Observations also lead to the conclusion that architects as a group reflect a high level of “computer anxiety.” Still, some of the most enthusiastic and creative computer users are architects, offering proof that automation can be of value to the profession.

The original purpose of this work was to identify the conceptual knowledge necessary for becoming proficient in the use of automated architectural drawing programs. It was felt that in accord with studies of cognitive development in such widely divergent fields as children’s arithmetic, tonal recognition in music, electronic circuitry, and creative writing, these concepts would be ordered according to a hierarchy of developmental stages. Once those levels were recognized and classified, the pattern of procedural errors made by the learner would indicate his/her particular developmental stage. Instructional programs in using
computerized drawing could then diagnose the student's error pattern and begin at his/her level. If the solution to the delayed adoption of automation by architects lies in better training methods for using computerized drawing tools, observations of people learning to use a computer aided drafting (CAD) program, i.e., case studies, should supply insight about how to do that.

As the study progressed, other factors that affect the training of architects to use computers became apparent. The case-study approach also provided the environment to observe any additional influences on architects' computer usage. The results of the study demonstrate that the mental model of the drawing process dominates the architect's learning and subsequent use of computerized tools. Educators and software developers need to keep this model in mind if they expect to optimize architects' participation with computers.

Knowledge Elements

Operational mastery of a technical skill is customarily described as having two components: 1. procedural competence and 2. conceptual understanding. Using computerized drawing programs requires that procedures such as draw, erase, move, copy, and other processes common to all programs be learned. Different systems employ slightly different input sequences and parameters which must be executed correctly for the program to work. Some procedural information may be obtained from previous experience and may influence the learning of a new program by reinforcing or inhibiting the acquisition of the new technical skill. Past experience may also influence the method used to execute a procedure or the selection process that the user employs in choosing procedures to accomplish a particular goal.

The conceptual framework needed to support procedural learning includes some factors common to the use of computers in general as well as those particular to graphics applications. Those would include the command structure, interaction with a computer through prompts and menus, screen coordinates, computerized drawing tools (map, grid, etc.), in addition to the concepts involved with data storage as related to drawing elements. These concepts facilitate the execution of procedural skills and also the efficient learning of new procedures. Conceptual knowledge may be employed in solving new problems as they arise, interpreting new contexts and employing innovative approaches.

By observing procedural errors, knowledge can be gained about the user's misconceptions (Shaw, Standiford, Klein, & Tatsuoka, 1982; Shaw, 1984). For example, a learner who habitually ignores the prompt line may not understand interaction with the computer. There are many different types of prompts in most computer graphics programs and teaching a student to respond correctly to one kind may not solve the problem for other types unless his/her conceptual impediment is corrected.
The problems seen in the use of architectural drawing programs did not seem to be completely explained by reference to education about procedures and their underlying concepts. This conclusion led us to a consideration of the mental model of the drawing process as held by most architects. This element has been defined by Cott, Bennett, & Gillet (1986) as, "a relational model or an internal representation of a complex structure in terms of the interrelatedness of its component parts." Drawing is strongly influenced by physical, cultural, and cognitive factors (Van Sommers, 1984). Architects would be expected to hold well developed mental models of the drawing process since their established means of communication has been through drawings. If the model of drawing that the architect holds is in conflict with the drawing model implemented on the computer, some resistance can be expected. However, some architects seem to have resolved the problem, probably through extension of their mental models. An understanding of such mental models is a necessary part of the knowledge base for teaching architects to use computerized drafting and drawing systems.

The Observational Tool

The observations were made using two beginning computerized lessons for AutoCAD (Shaw, 1986). The completely on-line lessons were constructed from scripts and predesigned drawings to lead the students through a series of procedures and concepts to the point where they are able to proceed independently using online help and the user's manuals. The objectives of the two lessons are:

Lesson 1. Procedures: erase, draw (lines, arc, circle, trace)  
Concepts: command, menu, window, coordinates, grid, snap, ortho, redraw, on-line help

Lesson 2. Procedures: move, copy, zoom, pan, view, set, color, linetype, new  
Concepts: drawing area, displacement, base point, layering

The procedures and concepts are presented by example, after which the student is allowed to experiment, continuing at his/her own pace. An abbreviated version of the AutoCAD menu is used. There are questions about the arc and trace commands in the first lesson and about move, pan, and zoom in the second lesson. Figures 1 through 3 show examples from the lessons.

Sampling

Eight architects, four computer specialists associated with architecture, six construction-related engineers, and one architect specializing in computer science were observed in sessions varying in length from 20 minutes for both lessons to 1 hour for one lesson. The subjects were volunteers from the U.S. Army
AutoCAD is controlled by commands.

Or you may type a command at the prompt.

Command:

Figure 1. Start

Layer BLUE
Drawing involves points and their relationships.

From point
7,7

To point
7,5

Draws a vertical line on the screen.

The LINE command draws from point to point.

To draw the closing line accurately, select "close" from the LINE options.

Figure 2. Line
Layer RED  46.75.B.21
Look at the HELP pages and experiment with:  ARC
    CIRCLE  TRACE

The function keys make it easy to use these features:

Command: circle
3P/2P/Center point: 2p
First point on diameter:

Figure 3. Draw

Layer CYAN  5.24 (34)  
When drawing a closed figure, you may connect to the beginning with "close". Otherwise, tell the computer when you are finished drawing by pressing ".

Try some lines before you continue. Select DRAW and then the LINE command. Use the crosshairs to select your points. Remember how to erase if you need it.

From point:
To point:
To point:

Figure 4. Sketch
Construction Engineering Research Laboratory who were interested in learning AutoCAD.

Measurement Criteria and Standards

Criteria such as response time, tendency to follow directions (implied and explicit), experimentation with the commands, independence, and initiative, as well as errors committed, were noted. Questions asked by the subjects and answers to questions asked by the observer, in addition to free comments were recorded. Some of the subjects were asked to perform additional drawing exercises as will be described later.

The classification of procedural errors with respect to conceptual knowledge was made by trying to associate clusters of errors with their probable cause. An attempt was also made to model an expert lesson user by establishing a standard for constructive use of each presentation in the sessions. This modeling proved to be difficult because of the differences in goals, experience with computers and/or drawing programs, and learning styles exhibited by the subjects. However, particular points in the lessons (to be described later) proved to be valuable in pinpointing specific differences among users.

Observations

In reporting observations, the background of each subject will be identified by (A): architect, (C): computer specialist, and/or (E): engineer. (1) indicates that the subject completed education within the last 10 years; (2) signifies that education was finished more than 10 years ago. In the AutoCAD lessons, subjects were free to do any experimentation they chose using the commands read from the menu or even trying commands that they thought might be available based on past experience. There were no constraints or rules, though occasionally rules were implied. See Figure 4. The following examples include both predicted and unanticipated responses to the computerised instruction.

Subject S.A. (C,A-1) proceeded slowly, reading each screen carefully during the first part of the lessons. He suggested that additional instructions be added on different pages and wanted every detail spelled out for the user. Toward the end of lesson 2, however, he decided to examine parts of the drawing more closely and, after zooming in a small portion, he paused away from the display. As he became involved in the experience, he stopped worrying about the procedures and chose to experiment.

H.W. (C-1) had a preconceived notion about how to use the computer program. She tried many experiments, even many that were not in the directions. On the sketching page, Figure 4, she drew her lines across the text rather than inside the box. All commands on the menu were tried, in addition to the ones described in the examples. She often seemed to have a drawing goal, such as in the arc command. When the arc didn't behave as expected, she...
seemed challenged and tried to make it go the other direction. The instructional text was only used as a general guide to finding out what the program did.

Students Z.G. and Q.G. (C-1) both demonstrated the goal of understanding the computer program. They tried the examples only when they felt uncertain about their results. However, the understanding was not always accurate. Z.G., for example, could not answer the questions about the behavior of the arc and trace commands without some last-minute experimentation. During the second lesson, when the subject of using shortcuts was stressed, Z.G. suddenly commented, "That's what this program is all about, isn't it! Shortcuts." They both reacted very quickly to the computer and completed the lessons in less than half an hour.

S.H. (E-1) had begun using AutoCAD from a tutorial manual. The manual didn't explain how the screen examples were constructed, so most of his comments were focused on how easy this lesson seemed to be. He expressed the desire to work through examples completely and knew how each step worked. Drawings done in a preset environment made him uneasy. He had already done some advanced commands, but he erred when indicating the end of a selection set, demonstrating that his conceptual knowledge of the program was not yet solid.

R.A. (A-2) was very hesitant about doing the lessons. He tried every command in the lesson very slowly and completed the first lesson in one hour. Amid comments about how he hates computers, he inserted several remarks about how this would be the way to learn AutoCAD (if you had to learn it) rather than from a book. He stated that he had a book and meant to get started before, but the book proved impossible to read. On the sketch page, he started to draw in the box, but later drew some lines outside. He seemed surprised that the program would allow him to do that. Even after the hour-long session, R.A. had trouble recognizing the prompt for entering a command. In conversation he revealed that he has a computer at home, but doesn't really use it.

Subject Q.K. (A-2) said that he had had some experience with AutoCAD. In fact, he taught architecture and required his students to learn this program. He did so by recommending a book and letting them teach themselves. He seemed surprised by some of the drawing tools in the program, such as "blip" marks and the ability to set the snap. He finally stated that he hadn't had much time for the program himself and thought this might be a good way to learn it. He seemed to enjoy experimenting with the commands in the lesson, drawing on almost every page - including outside the sketch box. He moved rapidly through the lesson, often missing prompts and return presses.

A.A. (E-2) hurried to read a tutorial on AutoCAD the night before the scheduled session. She felt confident that she understood many of the commands, having had experience with
computerized drafting programs. She readily tried the commands that she recognized, not really seeming to want to experiment with others. Lines and close were executed inside the sketch box with careful precision, a circle and one arc drawn when directed. Since there was no experimentation with arc or trace commands, she couldn't answer the questions in the lesson. She always read the prompt line and responded quickly. After the first lesson, she asked to take the second one to her own computer.

H.A. (E-1) worked slowly and carefully, following the directions precisely. She showed great satisfaction when the commands worked as she expected. She asked questions about what would happen in certain cases, but did not experiment to test them. She drew only inside the sketch box and read the online help pages. She completed one lesson in 40 minutes and asked to come another time for the lesson 2. When she returned, she reported having tried several things in a book and had a few questions about them.

Q.T. and S.A. (E-1) worked through the lessons with obvious precision, doing each example carefully and moving on. Neither one did much experimentation, however Q.T. did draw outside the sketch box after asking if it was alright if he did. B.H. (A-1) also worked quickly and seemed to be comfortable with the computer. He tried examples and did some exploration with the commands on the menu. All of these subjects were graduate students or had recently graduated.

R.V. (E-2) was hesitant at first, but seemed to warm up to the idea of learning to draw from an online lesson. He was not very responsive to the prompt line at first, but improved as he went along. He was observed to recite, "Now it wants me to use a command," and other rules as he proceeded. He drew inside the sketch box, but seemed interested in the question of whether that was required by the program.

Subject Q.V. (A-1) was very enthusiastic about the capability of the drawing program. He seemed excited about almost every feature, from setting the snap and grid to the many different ways to draw arcs. On the sketch page, he selected a spot in the center of the box and then proceeded to drag a circle outside the box before fixing it. When asked why he did that, he responded, "I just wanted to see if I could." While he did seem to have trouble with responding to some prompts, he improved as the lesson progressed. When he got something to work, he repeated it immediately.

H.A. (A-2) admittedly had trouble with the expectations of the computer. He wasn't relaxed about the command prompt even after completing the lessons. He expressed his feeling that students are better at using computers than he was (he is a professor of architecture) but he felt a compulsion to use the computer. He had worked with an authoring system extensively to write student instruction. During the online lesson, he was more interested in trying his own ideas than in following the
sequence. He seemed to lose track of the objective on the page and browse through the menu. He drew wherever and whatever he wanted on each page and seemed to have some drawing goals in mind. However, at times he seemed to "give up" when the results didn't please him, moving ahead to another example.

S.V., Y.Q., and B.Y. (A-1) were all recently graduated architects who had attended a short workshop on AutoCAD several months before the sessions. They had not been working on computers since the workshop and came for review. They all followed the instructions carefully and experimented with the commands quite a bit. All three of them tried to draw figures or designs. S.V. drew the front of a building on the sketch page. B.Y. had a little trouble classifying commands on the menu but on the whole, none of them had trouble.

Y.V. (B-1) had not used AutoCAD before, but had some experience with computers. He worked through the lesson, looking up several things on the on-line help and trying the commands. He followed directions carefully to make a layer, give it color, make it current, and try drawing on it. He expressed no surprise when the computer screen then continued with his assigned color.

Only one subject E.G. (C-1) seemed to have serious problems with progress through the lessons. She seemed to be uninterested in the instructional sequence, perhaps being more motivated to find out what the program did. She had trouble reading the instructions and did not watch the screen. Some of the concepts depend on watching the command demonstrations, and she wasn't aware of that. Understanding the three ways to select items for erase, move, and copy (as well as many more advanced commands) is essential for using the program, but she was waiting to be told about the program, watching the observer rather than the computer screen.

Problem Areas

Only three subjects used online help the first time it was suggested. The screen that recommended it gave only short descriptions of the screen tools: axis, grid, snap, ortho, and blipmode. The users seemed to feel that they knew what the tools were and didn't concern themselves with how the program expected the commands to be used. Some of the subjects had read reference material about the commands, but most of them seemed to ignore any potential problems. Even when they were specifically instructed to consult the help for circle, arc, and trace commands, only six of them did. The instruction was designed with the idea that making arcs was complicated enough and the trace obscure enough that most users would follow the directions. After the initial observations, a confusing direction about trace width was added to the screen, but still subjects were reluctant to look it up. Two questions were asked about the arc and the trace, and at that time three more subjects looked at the help when they were unable to answer the questions. They didn't consider help proffered by a
computer program an asset, possibly because of lack of experience or bad experience.

Using the erase command seemed to be very difficult for some of the subjects. When window or specific objects are chosen, items to be erased are marked by dotted lines. The selection set may be added to and particular objects may be removed before the Enter key is pressed and the actual erase is performed. This interaction between computer and user requires more than one step, which seems to be a surprising idea. Users do not expect the computer to display such complicated responses. It also may be that the operation of that command is not analogous to human behavior, a type of problem that will be discussed later.

Other problem areas that seemed to be related to the computer’s requirements were the use of the command prompt and pressing Enter when a typed response was completed. Since the lessons are constructed to rely mostly on the selection of commands from a menu, recognition of the command prompt is essential. Many subjects attempted to erase an object or mark a point for a line before they had selected the erase or line command. Some users reported that other programs did not require such a direction, but it is more likely that they just did not recognize the procedure as a general computer necessity. The computer must have a way to accept a command and the user must know when it has been accepted. The requirement to press Enter after typing a command was usually satisfied; however, a few subjects seemed to expect the computer to respond as soon as they completed the word, just as it had when they selected it from the menu.

The menu structure was fairly easily comprehended from the standpoint of submenus and commands. Differentiation between the names of submenus and names of commands was uncomplicated. There was some confusion about lists of options under commands which probably led to some of the command prompt difficulties mentioned above. A few subjects did have trouble associating commands with specific categories (e.g., move with edit).

The arc command caused enough trouble to merit closer examination. There seemed to be no problem as long as the student was drawing an arc as an example of an arc; the problems occurred when the arc was to be part of an actual representation. One of the subjects attempted to draw a happy face (figure 5). After drawing a circle, she drew the mouth (from left to right, counterclockwise) and then attempted an eyebrow using the same left-to-right direction. The computer, drawing counterclockwise, made the eyebrow under the supposed eye (figure 6). Several subjects were then asked to draw a happy face on paper and it was found that all of them drew the eyebrow from left to right in a clockwise direction. While the computer can draw clockwise and it can also draw the correct eyebrow several other ways, none of the procedures seem to emulate the human behavior. The human probably uses four pieces of data to draw the eyebrow: the location of the eyeball,
Figure 5. Happy Face

Figure 6. Unhappy Attempt
the start, the end, and the direction. Computers may use different data values for the arc, but they customarily require only three. Again it is evident that problems occur when computerised drawing does not follow the human pattern.

Problems encountered in move and copy were related to the selection set as found in erase. Difficulties in using pan, zoom, and layering were not apparent, since the only subjects who tried the commands were successful. Some subjects simply watched the screen display and others did not complete the second lesson under observation. During the presentation of layering, users could choose to make a new layer, assign its color and linetype, set it as the current layer, and try it out. Only four subjects did that without prompting. When the suggestion was made, four more tried the command, with the rest stating that they had done it before. They all gave the impression that the concept was not troublesome.

Comparisons and Contrasts

Several differences were immediately obvious between the architects and the engineers observed. The engineers seemed more comfortable with written instructions. They either referred to manuals before or looked things up after online sessions. Several architects expressed a preference for the computerised instruction over the books they had seen. This may be the result of educational emphasis in the different disciplines or the fact that people who choose to study architecture are more visually oriented than those studying engineering.

Engineers seemed to follow the online instructions more faithfully than did architects, though this was not invariably true. Architects did seem more likely to experiment with the commands, but they had a tendency to prejudge the command by its title. Most of the architects did not explore the trace command because, as one subject queried, "Doesn't that mean drawing over some lines?" The architects frequently seemed to have a particular objective in their experimental drawings, whereas engineers tended to produce a satisfactory, but context-free, example to fit the directions. The architects often tried to draw outside the sketching box (an implied rule) while the engineers were careful to stay inside the frame, at least on the first line drawing. The computer specialists were also inclined to draw anywhere they liked.

Architects seemed less familiar with computers and the requirements of computer interaction. However, seven of the eight stated that they thought they should learn more about drawing programs; one was an outspoken critic of computerization. As a group, the architects were more hesitant and made more errors than other subjects, but did more experimentation. However, maturity seemed to make a difference among the architects. Those who had recently completed their education seemed more comfortable with
the computer and were inclined to step through the rules of the program.

Conclusions

The errors fell into groups that might be categorized as: (1) computer fluency (2) command operation and (3) system relationships. Computer fluency problems were exhibited by forgetting to press the return key, failure to observe prompts, confusion of mouse buttons, extreme delays in response time, problems with the function keys and the crosshairs, and inattention to screen displays.

Errors in command operations caused errors such as incorrect selection of screen locations for drawing commands, failure to mark items for selection sets, inappropriate location of base points or displacement, confusion of zoom and/or pan principles, and inappropriate expectations (e.g., the delay in drawing in the trace mode or the direction of the arc).

Failure to use screen tools, reporting system and the general rules (as in the selection set) properly, and difficulties with the menu structure indicate misconceptions concerning system relationships. More study of these errors is needed to determine possible arrangements within a task specification chart which concerns itself with the prerequisite knowledge required for accomplishment of each goal (Birenbaum & Shaw, 1985). No doubt many of the errors noted include components from more than one error category.

The main problems that architects had in using the computerized drawing program seemed to stem from their mental model of the drawing process. The more experienced the architect, the more pronounced the problems seemed to be. It may be that the accomplished architect has reached a level of expertise beyond rules, decisions, and problem solving that makes it difficult to accept a new tool for accomplishing something that he/she does very well by methods that are second nature (Trotter, 1986). The inexperienced architect may still be in the stages described as "competent" or "proficient" when he/she is willing to make conscious efforts to learn rules. Architects' drawings at all levels of expertise tend to be goal directed and problems arose when the computer program did not fit the mental model of drawing to accomplish the goals.

Mature architects may consciously embrace computerization, but have problems in applying it to what they do. It is quite likely that architects cannot describe the processes by which they are able to design. They have a capacity for visualization of buildings and spaces that defies explaining and analyzing. The situation is similar to that of the poet, as discussed by John Ciardi who said, "knowing how to and explaining how are two very different terms." Production of poetry requires an environment of poetry, not the ability to explain how one writes poetry (Ciardi, 1963). As with the poet, the architect needs an environment of
drawing, and that environment is made up of elements recognizable by the architect and probably is not easily explained. But it is the explaining that would be required in learning to use a new tool. The development of skilled performance using computers would require that the practice of drawing again become self-conscious. Progress could then be made toward regaining the degree of automaticity that the architect already has when using familiar tools (Card, Moran, & Newell, 1983).

The situation might appear hopeless except for the fact that some talented architects have embraced computerization and are its strongest proponents. These persons have become captivated by the power and potential of computerized graphics. They are able to see that the computer can be an extension of themselves and that there is a parallel between what they do and what they can make the computer do. This kind of insight has been implied by several computer-using architects. The most obvious similarity between such architects is delight in using computers.

Recommendations

Task specification and hierarchial arrangement of conceptual errors will surely prove helpful in designing the sequence of instruction for the use of CAD and in diagnosing the conceptual level of users. However, much of the behavior of experienced architects may not be affected by such developments. The architect must be pre-disposed to construct a new mental model of the drawing environment or the environment must change to suit his/her model. This situation has implications for the education of architects as well as for computerized design software.

First, computer programs must give the architect confidence that he/she is in control. Any software that limits flexibility or user command over the environment or variables is likely to be counterproductive. Some such programs or special features are being advanced "to make it easier for architects." While features that facilitate computerized drawing should be an objective, the solution will not be found in reducing the number of possible choices for the user.

Since the architect is unlikely to resort to documentation to find out what the computer "thinks," a powerful factor in ease of use will likely come from making the computer program approximate the way the architect thinks. This condition will mean fewer frustrations and unpredictable results. To make this change, the drawing model must be further studied. Architects need to be right more often in their expectations about computer behavior.

Architects need more experiences that allow them to follow their instincts with computers. Papert calls the computer a "tool to think with," which properly describes the desired role for the computer (Papert, 1980). This experience might well be outside the CAD environment. As one computer-using architect explained, he has found that computers can do things the way he thought they
should be by writing graphics programs. While the formal experience of such programming is probably not necessary, experience with
L000 or another similar computer language may be helpful.

The architects in this study liked computerised instruction more than using books. Training should take advantage of this preference. Not only will it suit the learning style of the architects better, but it will give them more experience in using computers. The instruction, however, should not focus on teaching the "correct" procedures, but should give users the choice of different ways to solve problems that they might encounter. Better still, the lessons should aim to allow for exploration of problems of their own selection, offering guidance and sequencing when necessary. Teachers for architects should be selected from those who like to use computers. Just being educated in a world that uses computers will not solve the problem for the next generation of architects. Many of the young architects, trained by instructors who didn't use CAD themselves, displayed hesitation in computer use.

The most important factor in training architects is the attitude of educators and software developers toward that profession. The architect is a valued user and contributor to the field of computer graphics. He/she may have some characteristics of computer anxiety and may appear hesitant to embrace automation, but the reasons for such behavior seem justified. Architects need to be respected for their fears of dehumanisation and standardisation and recognised as capable and creative computer users.

References


