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ABSTRACT

Computer graphics and computer-aided design (CAD) technology is rapidly changing design and manufacturing in American industry. This paper sets forth a model of the individual difference factors which may impact task performance and affective reactions to the use of CAD technology. A standardized, scorable engineering task was developed which utilizes CAD technology, and a number of individual difference variables were examined with reference to the task. Results indicate that cognitive skills were strongly related to CAD engineering performance, user confidence, and perceived task difficulty. Experience and attitudinal variables were not found to be related to the measured outcomes. Implications for employee selection and suggestions for future research are not provided.

Introduction

Computer-aided design (CAD), utilizing interactive computer graphics technology, is rapidly changing the nature of the design and manufacturing of a wide variety of products. This relatively recent technology allows engineers and designers to use computer graphics to aid in the design of virtually any item. By designing the product on the computer, changes, revisions, redesigns, etc., can be done much more quickly than is possible through laborous manual drafting methods. It is projected that virtually all organizations engaged in design and manufacturing will be required to adopt CAD technology to remain competitive (Reiser, Gueutal, and Marcotte, 1982). As CAD applications become widespread, an increasing percentage of the workforce will find that the computer graphics applications have become an integral part of their job. It is critical, therefore, to understand those variables which underlie effective job performance when utilizing CAD technology. This research is among the first investigations to evaluate the correlates of effective CAD performance.

Literature Review

The need for a growing pool of educated and competent CAD users has been pointed out by both academia and the business community (Harris, 1981). The necessity of studying those factors which impact job performance when using this visually oriented technology is apparent if organizations are to maximize the productivity benefits possible through CAD systems. Unfortunately, virtually no published research specifically addresses the determinants of effective CAD performance. In the absence of reliable empirical information regarding the characteristics of effective performers, industry has had to rely on anecdotal stories, untested interviews, observation, and surveys to identify applicants who hopefully will be better performers (Norton, 1983).

The lack of empirical literature describing the determinants of effective CAD performance stems primarily from the fact that there are no agreed upon measures of actual job performance. The absence of criterion for measurement has seriously hindered research in this critical area. Consequently, the authors of this study were forced to develop a measure of CAD performance. This measure, the Computer Graphics Performance Test (CGPT), was designed based upon interviews with practicing CAD engineers, as well as academics involved in CAD software development. The CGPT incorporates critical elements of the engineer/designer's job in a scorable testing format.

A body of literature does exist related to other business-oriented uses of computers. For example, factors such as cognitive style, experience, and decision making behavior have been studied in the context of management infor-

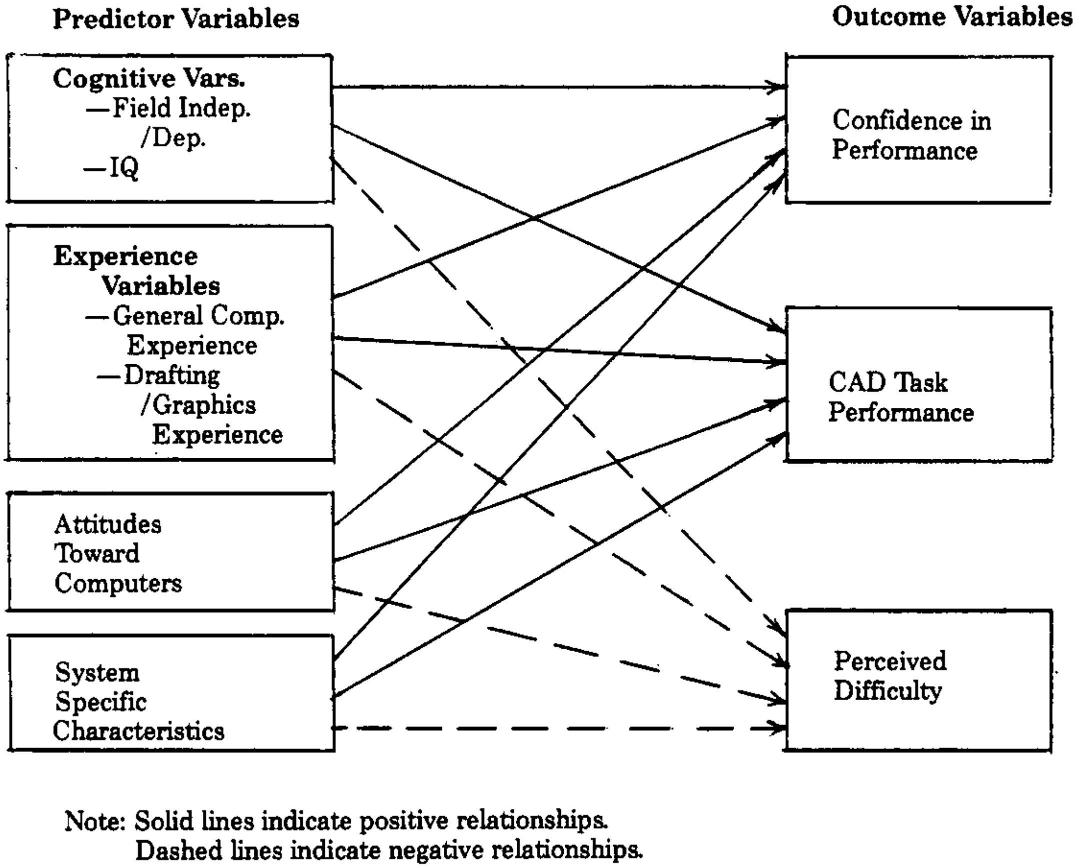

Figure 1

Proposed Model of the Determinants of Computer Aided Design Outcomes

mation systems (MIS). (For a review of this literature the reader is referred to Zmud, 1979.) Given the difficulty inherent in evaluating a complex technology such as MIS (Ginzberg, 1978; King and Rodriguez, 1978) the usual criterion measures have been attitudinal (e.g., user satisfaction), rather than actual job performance. Similarily, research on computer graphics has been restricted to attitudinal surveys of job incumbents and their managers (Norton, 1983). Human factors researchers have contributed to understanding user-system interactions (Shneiderman, 1979); however, much of this research has been restricted to questions of the physical characteristics of the system rather than user characteristics. Again, the typical dependent variables studied are attitudinal or fatigue-related.

Given the relative lack of literature pertaining specifically to CAD performance, the authors have developed a model of the factors which may impact job performance and work outcomes (Figure 1). This model is based upon theory and research from industrial psychology, interactive graphics systems, and the MIS area. It should be noted that the model is tentative and open to revision. Four classes of variables (cognitive, attitudinal, experience, and system design characteristics) are included as predictors of two types of outcomes: actual performance and affective reactions. The cognitive variables measured were general intelligence and field independence/dependence. The attitudinal measure consisted of an eight item "attitudes toward computers" scale. The experience variables were past drafting/graphics experience and general computer experience. CAD performance was defined as the number of correct responses on the CGPT; the affective outcomes measured were user confidence and perceived difficulty. A discussion of the hypothesized relationships between predictor and criterion variables follows.

The first set of predictor variables are related to cognitive skills. These skills are thought to directly impact the reasoning and perceptual processes of individuals (Zmud, 1979). In the present investigation, IQ and field independence were chosen to represent the two aforementioned components of cognitive skills.

IQ may be viewed as a measure of reasoning ability or general intelligence. Past research (cf. Zmud, 1979) suggests that cognitive skills such as general intelligence have a direct effect on decision performance using an MIS. It seems reasonable to suggest that the user's ability to make reasoned judgements will also impact CAD task performance. In CAD work, users must associate several items of visual information and, through a process of analysis and elimination, determine the correct response. Individuals with higher IQ should do better on the task, as well as find the task less difficult and have greater confidence in their judgements.

Field independence/dependence is a cognitive perceptual skill which describes the ability of individuals to extract information from a complex visual field. Field independent individuals are more easily able to disembed a simple shape from a complex pattern. That is, they tend to perceive stimuli is presented. Research dealing with MIS has reported that field independent users performed better than field dependent users in an interactive problem solving task utilizing visually portrayed information (Benbasat and Dexter, 1979). Given the highly visual nature of CAD work, involving sophisticated line drawings, it seems reasonable to suggest that users who can more easily disembed specific portions of a drawing from the visual field will be more effective performers. For example, field independent users should be able to separate out the lines on a given geometric plane from a three dimensional drawing more easily than field dependent users. Given their perceptual skill, field independent users are also hypothesized to find CAD tasks less difficult and have greater confidence in their judgements.

The attitudinal variable, attitudes toward computers, was included in the model based upon a relatively large body of theory and previous research which suggests that attitudes impact behavior. In this case, it is hypothesized that users who had negative attitudes toward computers would view the task as more difficult, be less confident in their judgements, and perform more poorly than users with more positive attitudes. Support for this hypothesis may be found in research by Norton (1983), Stone, Gueutal, and MacIntosch, (in press), and Walther and O'Neil, (1974).

The experience variable was defined by two measures: graphics experience and experience with computers. Users with drafting or graphics experience were expected to perform better than those without such experience. These users should also have less difficulty in making judgements and exhibit greater confidence in their decisions. This expectation is based on past research by Benbasat *et al.*, (1981), Chafin and Martin (1979), cited in Benbaset *et al.*, (1981), and Wather and O'Neil, (1974). Experience with computers was likewise expected to be positively related to task performance and confidence, and negatively related to perceived difficulty.

The final variable included in the model is system design characteristics. These characteristics include "user friendliness," software sophistication, ergometric design of equipment, physical and social work environment, etc. This variable is included in the model as it clearly impacts the outcome variables. In the present research however, system design characteristics were held constant. The focus here is on user characteristics which impact performance and affective reactions.

The following section provides the specific hypotheses tested in this study. These hypotheses are drawn from the literature and provide a test of the relationships shown in the proposed model. For each of the task outcomes the relevant set of predictor variables, the relationship between attitudes toward computers and degree of computer experience is assessed. It should be noted that the independent variable, "system design characteristics," is not examined here, as this was held constant in this research.

Hypotheses

H_1: Attitudes toward computers will be positively correlated with the degree of computer experience.

H_2: Performance on the Computer Graphics Performance Test will be positively related to attitudes toward computers, degree of computer experience, graphics experience, IQ, and field independence.

H_3: Perceived task difficulty (on the CGPT) will be negatively related to attitudes toward computers, degree of computer experience, graphics experience, IQ, and field independence.

H_4: Confidence in the quality of the user's decisions will be positively related to attitudes toward computers, degree of computer experience, graphics experience, IQ, and field independence.

Method

SUBJECTS

The subjects for this study were drawn from graduate and undergraduate classes at a technically-oriented northeastern university. A total of 69 individuals, 50 male and 19 female, participated. The mean age of the subjects was 23.7 years. Graduate students constituted 37.7% (n=26) of the sample and undergraduates 62.3% (n = 43). Subjects were classified as having either technical or nontechnical training. Technically trained subjects were 74% of the sample and nontechnically trained individuals were 26% of the sample. Virtually all subjects had used mainframe computing systems in their coursework and/or job.

Each subject participating in the study received a small amount of extra credit toward their course grade. An alternate activity was provided for any individual who wished to receive the extra credit, but prefered not to participate in the study. All subjects signed an informed consent agreement prior to the study. Of the 69 subjects who agreed to participate, usable data was obtained from 66. The criterion data for three subjects was lost due to computer failures.

MEASURES

Four measures were employed in the present investigation. These were: the Wonderlick Personnel Test, the Group Embedded Figures Test, a demographic and computer experience questionnaire, and the Computer Graphics Performance Task. Each of these measures is discussed below.

The Wonderlick Personnel Test is a commonly used test of general intelligence. Three facets of IQ—verbal skills, quantitative skills, and reasoning—are assessed in this measure (Wonderlick, 1978). The version used in this study was Form I, 1981 revision. Subjects had 12 minutes to complete as many of 50 items as possible. The total number correct is used as an index of general intelligence. In the present research, scores ranged from 21 to 50. The mean score was 29.97 (sd = 56.8). This mean compares favorably with those reported for samples of engineers and college graduates (reported mean = 29). The Wonderlick has been used in a variety of employment settings and has been shown to be related to job performance across a range of jobs (Wonderlick Associates, 1982).

The Group Embedded Figures Test (GEFT) (Witkin, Oltman, Raskin, and Karp, 1971) is a paper and pencil test used to assess the degree of field independence/dependence among subjects. The test requires subjects to correctly identify target outlines embedded in complex geometric patterns. Individuals who can accomplish this task successfully are considered field independent. The test is divided into three sections. The first section is composed of 7 items, and the second and third sections are composed of 9 items each. Subjects are given two minutes to work on section I and five minutes for each of the remaining sections. The first section is a practice test and is not used in scoring. Past research (cf. Witkin, Oltman, Raskin, and Karp, 1971) indicates split-half reliability coefficients of approximately r = 0.80. The correlation of parts II and III in the present study was r = 0.57. With regard to the performance of the subjects in this investigation compared to normative data, subjects in this study appear to have performed somewhat better. The mean number correct in this study was 14.6 (sd=2.93, range 3 to 18) compared with a national mean of approximately 11.3. This above average level of performance could serve to attenuate the relationship of GEFT scores and the criterion variables studied.

The demographics and computer experience questionnaire was designed to collect background data and specific information regarding experience with computers and graphics. Items pertained to computer-related educational and work experience, leisure computer use, experience with drafting and graphics, and attitudes toward computers. Based upon this questionnaire, several of the predictor variables included in this analysis were computed. These predictors are described below.

Degree of computer experience was defined as the number of hours of computer experience reported by the subject. This was based on computer-related coursework completed, plus the number of hours of computer-related occupational experience. Degree of graphics experience was defined as having had past course work in computer graphics or drafting, or using graphics in the course of their daily work. Subjects having each type of experience were coded 1, those without were coded 0. The codes were then summed to create a drafting/graphics experience score for each subject. The attitudes toward computers scale was composed of 8 likert type items and was based on previous research (Stone, Gueutal, and MacIntosch, in press). The reliability (internal consistency) of the scale was α=.77. Prior to the use of the demographic and computer experience questionnaire, the measure was pilot tested to ensure clarity in the instructions.

The Computer Graphics Performance Task (CGPT) was specially designed for the present study. The scores of subjects on this task were the CAD performance measure. This test assesses the subject's ability to integrate computer-generated two-dimensional graphic information and correctly identify a three-dimensional (isometric) engineering drawing. Based upon discussions with engineers currently utilizing CAD technology and academic researchers, it was felt that this task incorporates critical job skills required in CAD engineering jobs. Further, the ability to utilize two-dimensional engineering drawings and visualize a three-dimensional composite was considered a prerequisite of adequate job

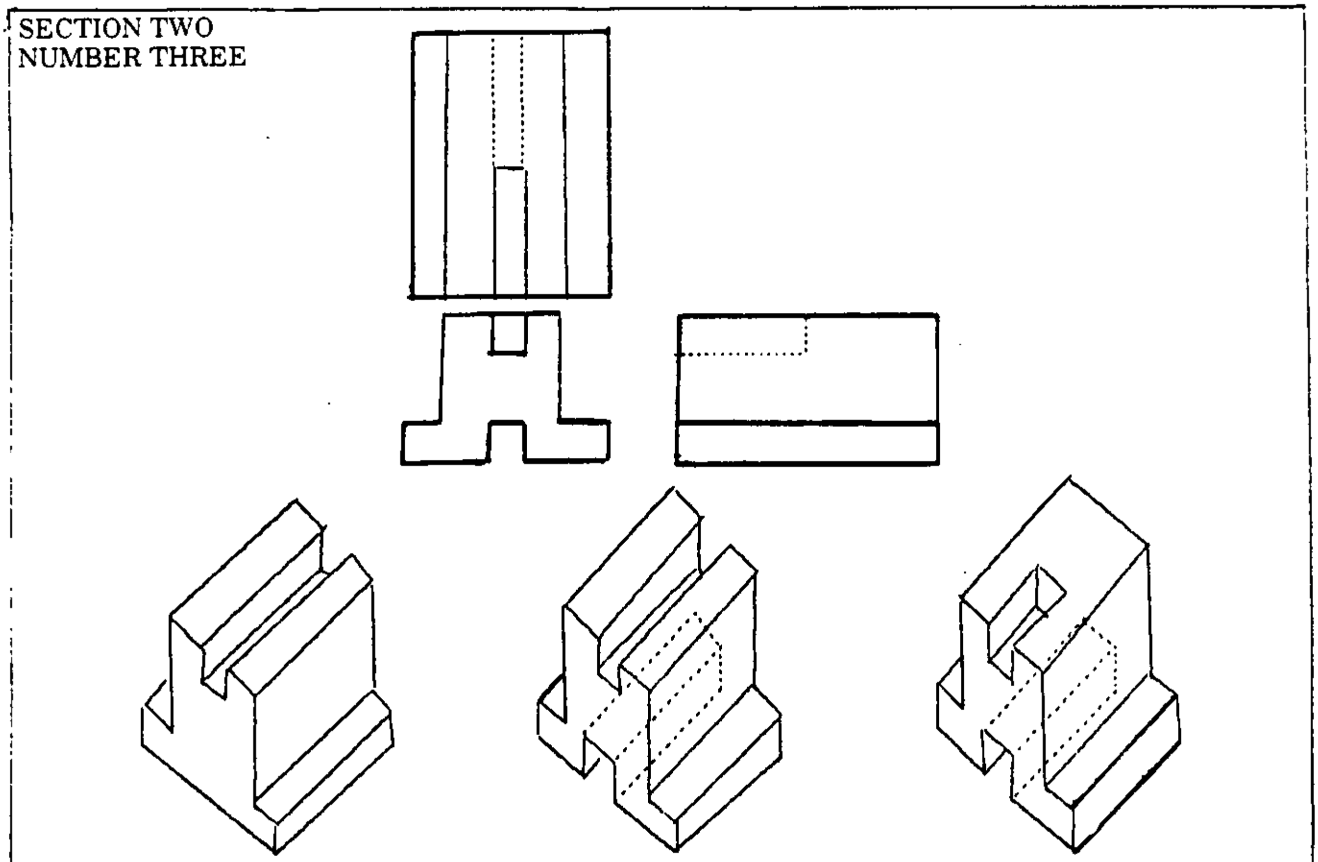

Figure 2
Sample Screen Image for the Computer Graphics Performed Test

performance. The CGPT does not assess total job performance, rather, it measures an important job-related skill.

Specifically, the CGPT presents subjects with top, side, and front views of an object and asks them to identify which of three three-dimensional views (also presented on the CRT screen) is correct based upon the two-dimensional information. The CGPT was composed of sixteen test items. Figure 2 presents a sample screen from the test.

The drawings included in the CGPT were based upon drafting problems commonly found in engineering and drafting texts, as well as actual mechanical devices designed with the aid of CAD technology. The sixteen screens (test items) included in the test were divided into four sections of four items each. The sections were designed to increase in difficulty from sections 1 to 4. The equipment used to design and administer the CGPT was a Prime 750 mainframe utilizing an IMLAC high resolution raster graphics terminal.

Subjects used a light pen to indicate which of the three dimensional figures they believed to be the correct solution. When the subject pressed the light pen against the image of the three dimensional solution on the screen, the system indicated the answer and asked for a confirmation. The response was then automtically recorded. Written instructions (read aloud) were used to standardize the administration of the task across subjects. Subjects were informed that they were being timed on the task, but that there was no time limit. Immediately after completing each item in the CGPT, subjects rated the perceived difficulty of the item, and the confidence they had in the correctness of the solution they designated.

PROCEDURE

The study was conducted in two sessions approximately one week apart. During session I, the informed consent agreement, demographic and computer experience questionnaire, the Group Embedded Figures Test, and the Wonderlick Personnel Test were completed. The order in which the measures were administered was counter-balanced across individual groups. Session I lasted approximately one hour and fifteen minutes. Session II involved collection of the CGPT data. A maximum of three subjects were run simultaneously on

Table 1

Correlations of Independent and Dependent Variables

	CGPT	Confidence	Difficulty	GEFT	IQ	Attitudes	Graphics Exper.	Computer Exper.
CGPT	———	.575 (.001)*	-.347 (.002)	.671 (.001)	.267 (.016)	-.011 (.466)	.131 (.149)	.142 (.130)
Confidence		———	-.529 (.001)	.451 (.001)	.166 (.093)	.064 (.312)	.192 (.063)	.106 (.201)
Difficulty			———	-.311 (.006)	-.133 (.146)	.032 (.406)	-.002 (.493)	.011 (.466)
GEFT				———	.099 (.214)	.064 (.312)	.289 (.009)	.132 (.094)
IQ					———	-.239 (.032)	.239 (.027)	.101 (.211)
Attitudes						———	.056 (.333)	.175 (.089)
Graphics Experience							———	-.024 (.424)
Computer Experience								———

*Values indicate probability level: example ($p < .xxx$)

the CGPT. Starting times were staggered so that each subject could be given individual instruction, and to ensure that all subjects understood the procedures. After all subjects completed both sessions of the study, each subject was provided with the opportunity to learn their scores and receive a description of the design of the study and the hypotheses.

Results

The data were analyzed utilizing multiple regression/correlation techniques to test the hypothesized relationships. The impact of the predictor set on each of the major criterion variables—user confidence, perceived difficulty, and Computer Graphics Performance Test performance—is discussed below.

The first hypothesis dealt with the relationship of computer experience to attitudes toward the use of computers in general. Specifically, attitudes toward the use of computers was hypothesized to be positively related to degree of experience with computers. This hypothesis was included in order to assess the degree of independence between attitudes toward computers and computer experience. A strong relationship between these variables would suggest that they be entered stepwise in the remaining analyses. However, since the zero order correlation between these variables was only $r = 0.175$ ($p < .089$, see Table 1), they will be treated as independent from one another in the remaining analyses. Hypothesis 1 is, therefore, very weakly supported in the present investigation.

The second hypothesis was that performance on the CGPT would be positively related to field independence/dependence, IQ, degree of computer experience, graphics experience, and attitudes toward computers. The results of this analysis are presented in Table 2. All variables were entered into the regression equation simultaneously. The multiple R for this analysis was

Table 2

Regression Analysis, Means, and Standard Deviations for Measured Variables

Predictor Variables	Criterion Variables: Attitudes	Confidence	Difficulty	CGPT	Mean	Sd
Attitudes	----	.037 (ns)*	.019 (ns)	.026 (ns)	36.5 [20-45]**	5.89
Computer Experience	.175 (.089)	.036 (ns)	-.004 (ns)	.021 (ns)	455.3 [0-1530]	234.95
Field Independence	----	.398 (.01)	-.312 (.05)	.617 (.001)	14.6 [3-18]	2.93
Graphics Experience	----	.028 (ns)	.092 (ns)	-.145 (ns)	1.0 [0-6]	1.49
IQ	----	.134 (ns)	-.106 (ns)	.284 (.05)	29.5 [21-50]	5.19
R_m	.175 (.089)	.452 (.026)	.321 (.301)	.671 (.001)		
R_m^2	.031	.204	.103	.450		

*Values indicate probability level: example (p<.xxx)
**Values indicate score range: example [xx-xx]

$R_m = 0.671$ ($p < .001$, $R_m^2 = 0.450$). Examination of the beta weight associated with each predictor indicates that two variables, field independence/dependence and IQ were statistically significant. The beta weights were: $B = 0.617$ ($p < .001$) for field independence/dependence and $B = 0.284$ ($p < .05$) for IQ. The beta weights for the remaining variables did not prove significant. Hypothesis 2 was strongly supported overall, however, not all the hypothesized variables appear to be associated with computer graphics performance.

The third hypothesis dealt with the relationship of perceived task difficulty to field independence/dependence, graphics experience, degree of computer experience, IQ, and attitudes toward computers. Specifically, negative correlations were expected between perceived task difficulty and these variables. As before, all variables were entered simultaneously. While the overall regression equation was not significant (see Table 2), the zero-order correlation between difficulty and field independence was significant ($r = 0.311$, $p < .006$) and in the hypothesized direction. This later finding lends partial support for Hypothesis 3.

The fourth and final hypothesis was that user confidence in the correctness of the solution designated would be positively related to attitudes toward comuters, graphics experience, degree of computer experience, IQ, and field independence. The multiple correlation coefficient for this analysis was $R_m = 0.452$, ($p < .026$). Examination of the beta weights associated with this analysis indicated a significant relationship between field independence and user confidence ($B = 0.398$, $p < .01$). Hypothesis 4 was supported at least with regard to the relationship between field independence and user confidence.

Discussion

The results of this investigation suggest that cognitive factors, defined here as perceptual skill and IQ, are important variables which impact user performance with computer graphics equipment. Specifically, these data indicate that the degree to which the user is field independent is highly related to success in making correct decisions using computer graphics technology, as well as user confidence and perceived difficulty. Attitudinal and experience factors were not found to be reliable predictors of performance, confidence, or perceived difficulty.

The results pertaining to cognitive skills are not surprising considering the nature of computer-aided-design work. Users are presented with rather complex graphic information and must base design and engineering decisions upon this visual input. The ability of job incumbents to effectively process this information may well depend upon two factors—perceptual skills and general reasoning ability. In this study, 43.1% of the variance in CGPT performance could be predicted based solely upon field independence and IQ. Equally important, user confidence and perceived task difficulty were found to be related to field independence ($r = 0.451$, $p < .001$ and $r = 0.311$, $p < .01$ respectively). This finding suggests that perceptual skills impact user confidence and affective reactions, as well as task performance.

It should also be noted that, since GEFT scores were somewhat restricted, the magnitude of the effects found in this study may underestimate the true correlation. That is, the findings with regard to field independence may be conservative estimates of the relationship between this perceptual skill and the measured outcome variables.

The present study does not provide support for the hypothesized linkage between attitudinal and experience factors as predictors of computer-aided design outcomes. Graphics experience was not found to be reliably related to task performance or perceived task difficulty. A weak relationship ($r = .192$, $p < .063$) was found between graphics experience and user confidence. This low degree of relationship was not expected considering the similarity between the CGPT and traditional drafting type tasks. One potential explanation for this result may be related to restriction of range on the graphics experience variable. Of the 66 subjects who took part in this investigation, only 13 (24.5%) were classified as having any graphics experience. Further, those classified as having any graphics experience may have had as little experience as one course in high school. This may have attenuated the relationship between these variables. Future research should examine the relationship between graphics experience and computer-aided design performance utilizing a sample of individuals who exhibit a greater range of drafting/graphics experience. The use of a continuous variable to index graphics experience is also suggested.

The hypothesized relationship of general computer experience to the outcome variables CGPT performance, perceived difficulty, and user confidence was not substantiated. The zero order correlations were: $r = .142$ ($p < .13$), $r = .011$ ($p < .466$), and $r = .106$ ($p < .201$) respectively. This lack of significant association may not be attributed to a restriction of range problem, since the range of computer experience was quite broad. This range should allow a reasonably strong test of this hypothesis. It appears that general experience with computers does not lead to greater success with computer-aided design equipment. This finding does not address the issue of the role of actual computer graphics experience as it impacts performance, perceived difficulty, and user confidence. Future research should examine the role of CAD work experience and the aforementioned outcome variables.

Attitudes toward computers, likewise, was not shown to be predictive of the outcome variables included in this research. Examination of the correlations of the attitude scale and the outcome variables reveal no significant relationships. The largest correlation was not with one of the criterion variables, but rather with IQ. A negative correlation ($r = -.239$, $p < .03$) was found. Apparently, the higher your IQ the less positive you are about computers. Future research should examine the role of specific attitudes towards computer-aided design technology as a predictor of CAD related outcomes.

Several limitations on the present research should be noted. First, the Computer Graphics Performance Test is a recently developed criterion measure. The content of the CGPT can be argued to be highly job related, since the stimulus drawings are based on design problems and CAD created components. However, while it was designed to tap job related skills associated with computer assisted engineering design work, the extent to which the CGPT is empirically related to job performance remains undocumented. Clearly, the CGPT does not assess all the job related skills required of engineers and designers utilizing CAD technology, rather it measures a necessary, but not sufficient CAD job skill. Future research will seek to link performance on the CGPT with measures of actual CAD engineering performance.

The second limitation concerns the representativeness of the sample. The subjects employed in this study were students. While the results pertaining to cognitive skills should not be effected by the nature of the sample, the attitude and experience variables may be. That is, the majority of the individuals included in this research may not have had sufficient opportunity to develop graphics experience of task-related attitudes. This could be responsible for the lack of significant relationships between these variables and the outcomes included in this research. However, the cognitive skills of IQ and field independence/dependence are enduring, non-experience based individual attributes. As such, the results pertaining to these attributes are probably the most generalizable findings of this research.

Conclusions and Implications

Computer-aided design utilizing computer graphics is rapidly becoming the technology of choice for the design of a wide range of products. Projections indicate that virtually all organizations engaged in design and manufacturing will be required to adopt CAD technology to remain competitive (Reiser, Gueutal, and Marcotte, 1982). This technology is quickly maturing and decreasing in price. Virtually any organization will be able to acquire the equipment; those organizations that are able to use the technology most efficiently will stand the greatest chance of long-term success. This research provides some of the first empirical findings related to factors which impact individual performance in using this important emerging technology.

Three sets of predictor variables (cognitive, attitudinal, and experience) were investigated as they related to three outcome variables (task performance, user confidence, and perceived difficulty). The results indicate a rather strong relationship between cognitive skills, especially perceptually related skills, and the outcome variables. Attitudinal and experience variables did not appear to be reliably related to the measured outcomes. These findings, if substantiated through future research, suggest that increased emphasis should be placed on the assessment of cognitive and perceptual skills in those individuals who wish to use CAD equipment. Career counseling for individuals contemplating entering a job field requiring daily work with CAD equipment should utilize various measures of cognitive and perceptual skills in the counseling process. It may be the case that some individuals are less likely to be successful in jobs requiring the use of CAD due to their cognitive skills. Employers may wish to include such measures in the assessment of the potential job success of applicants for positions requiring CAD equipment use. The predictive validity of selection systems may thereby be enhanced by including measures of cognitive skills. Likewise, if the CGPT is shown to be empirically related to job performance, it may be utilized as a selection technology.

Clearly, a great deal of research remains to be conducted before a complete understanding of the factors which underlie performance in utilizing CAD technology is realized. The results reported here represent pilot research utilizing a newly developed CAD task. As such, generalizations from these data must be made very cautiously. Other cognitive/perceptual variables such as cognitive complexity, and visual acuity should be studied. Likewise, additional experience and background factors (e.g., specific coursework, years of work experience, experience with a variety of computer systems) should be studied. Research should also employ samples composed of job incumbents actively engaged in CAD work. The results of such research efforts will help to ensure that this new and critical productivity enhancing technology is effectively used.

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