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ABSTRACT

The question studied whether the specific seven TICCIT system colors used within color coding schemes can be a source of confusion, or not seen at all, by the color-blind segment of target populations. Subjects were 11 color-blind and three normally sighted students at Brigham Young University. After a preliminary training exercise to acquaint the subjects with the TICCIT terminal, keyboard, and use of the systems's colors, subjects completed a color coding test which required them to match color coded responses with color stimuli. Students were then given a short questionnaire to assess color presentation preferences. A subject error in the test was defined as a color coding response different than the stimulus color given. Confusibility of the seven TICCIT system colors was determined by subject color coding errors tallied into a color combination matrix. Task and questionnaire results indicated confusion among color-blind subjects in green-yellow, white-cyan, and red-black color coding combinations, while normally sighted subjects had no real trouble with any of the combinations. In addition, color-blind students felt that color was desirable in instruction if used sparingly and logically. (CMV)

INSTITUTE FOR COMPUTER USES IN EDUCATION

COLOR-BLINDNESS STUDY: COLOR DISCRIMINATION ON THE TICCIT SYSTEM

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DIVISION OF INSTRUCTIONAL RESEARCH, DEVELOPMENT & EVALUATION
Brigham Young University
Provo, Utah

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Richards and Macklin (1971) estimated that color coding may be a source of confusion, or not seen, by about 8 percent of men and .5 percent of women. TICCIT courseware, thus far, has depended on color coding as: 1) a means of idea isolation; 2) a means of organizing; and 3) occasionally as a means of adding variety. The problem is whether the peculiar TICCIT system colors within the color coding schemes will be a source of confusion, or not seen, by some segment of the target populations.

Thuline (1964) indicated a possibility of putting color deficient grade school students at an unrecognized disadvantage by using color in teaching. In the study a survey of 10,341 grade school students was made. A larger proportion of color deficient children appeared to have learning and behavioral problems. A study by Dannenmair (1972) gives some support to the idea that color deficient high school students may also have learning problems. Scores on a color-blindness test, I.Q. scores, and semester grades in a high school biology course were correlated for 81 students. No relationship was found between I.Q. and color-blindness, however, a strong negative relationship was found between color-blindness and semester grades in biology. In a correlational study by Lorenz and McClure (1935) it was found that no relationship existed between intelligence scores, color-blindness, and academic success in college students. This appears to contradict the Dannenmair study and the findings by Thuline. The contradiction is cleared up in seeing that biology is highly filled with color, while general academic success is probably quite independent of perfect color discrimination. To read a book with black print on a white paper can be discriminated easily even by the color-blind.

TICCIT courseware may be easily correlated to the Dannenmair study in predicting that in general academic work, the color-blind student will appear no different that the normal propulation, but with TICCIT color coded material, he may have problems. However, these problems may be lessened if color confusions can be identified and avoided in TICCIT courseware. The identification of these color confusions on the TICCIT system was accomplished by the following:

METHOD

Confusibility of the seven TICCIT system colors was determined by subject color coding errors tallied into a confusion matrix. An error was defined as a subject response (color coding in a subject selected color) different than the stimulus color given. Each color, crossed with itself and all other colors in a confusion matrix indicated which colors are confused with which others.

Eleven color-blind Brigham Young University students were the color-blind subjects. Ten were male, and one was female. Three normally-sighted BYU students were also used for comparison to the color-blind S's responses. Two of the normally-sighted students were female and one was male. Color-blindness was determined by the scores on the pseudo-isochromatic plates.

The apparatus used was a TICCIT terminal consisting of a television display and the special user keyboard. Materials such as colored marking pens and response sheets were also provided.

PROCEDURE

An advertisement was placed in the BYU campus newspaper; the Daily Universe, on February 12 and 13, 1974. Respondents to this ad, 17 in number, were scheduled for the study during the following week. Eleven of the respondents were used. Three normal subjects were also used to compare against.

The pseudo-isochromatic color-blindness plates were presented to each subject. The results of this test are presented in Figure 1 shown on the following page.

In a short pre-training session (see Appendix A), the students were introduced to the colors and the color names on the TICCIT system by demonstrating two preliminary color coded pages. The seven colors of the TICCIT system were pointed out to each subject. Paper copies of the two preliminary

COLOR-BLIND SUBJECTS

Student	Red-Green	Blue-Yellow	Total
1	28.5	5.5	34.0
2	23.0	6.0	29.0
3	28.0	2.0	30.0
4	28.5	6.0	34.5
5	27.5	6.0	33.5
6	29.0	6.0	35.0
7	29.5	6.0	35.5
8	27.5	5.5	33.0
9	30.0	6.0	36.0
10	22.0	6.0	28.0
11	21.5	5.0	26.5

NORMAL SUBJECTS

Student	Red-Green	Blue-Yellow	Total
1	0.5	0.0	0.5
2	0.0	0.0	0.0
3	5.5	0.5	6.0

Figure 1: Summary of Errors on Pseudo-Isochromatic Plates by Student

television displays, as well as paper copies of ten stimulus displays to be presented following preliminary training, were given to the student (see Appendix B). The paper copies of the stimulus material were black and white and contained none of the color codings that appeared on the screen. Each word and punctuation of the stimulus material on the screen was randomly assigned one of the seven system colors. The subjects were shown six colored marking pens which corresponded to six of the seven colors on the TICCIT system. Black had no pen to represent it. In the pre-training session the subjects were shown how to mark the paper copies with the colored marking pens so that they corresponded to the color codings of the same material as it appeared on the TV screen. As practice, they were allowed to mark the paper copies themselves with the experimenter guiding them. The colored marking pens were each labeled as to the particular system color that they were to be used for. When the pre-training session was completed, the subjects then proceeded to work through ten more pages of color coded stimulus material, color coding the paper copies as they had been instructed in the pre-training session. After a subject completed the color coding task, he was asked to complete a short questionnaire (see Appendix C).

RESULTS

Confusion Matrix: Errors in color identification were scored using a transparent overlay key, and tabulated in a confusion matrix (see Appendix D). The results from the color-blind subjects were combined and the error counts were converted to error probabilities, as shown in Figure 2 on the following page. The same was done for the normal subject responses. The probability in each cell is a conditional probability of the form: Prob. { Rx/Sy }, which can be expressed in words as: given stimulus color y, what is the probability of obtaining response x? In addition to the cell probabilities, the overall error probabilities for each color were calculated. They appear in the extreme right-hand column of Figures 2 and 3.

Figure 2 shows five color combinations as significant. Significance is set at the .05 level. The difference between traditional statistic uses of the alpha level and the use of alpha in this study is that to be significant, the score must be above .05 rather than below. In other words five times or less out of a hundred will be counted as a chance error while any more errors than five out of a hundred is then considered not to be chance, but a significant problem point. In order of significance, the following color confusion probabilities were found:

Stimulus	Response	Error Probability
Green	Yellow	0.3930
Cyan	White	0.2591
White	Cyan	0.2239
Yellow	Green	0.1168
Red	Black	0.1089

Stimulus Color Given	Response							Overall Error Probability
	Red	Green	Yellow	Blue	Black	Cyan	White	
Red				0.0016	*0.1089		0.0008	*0.1113
Green			*0.3930	0.0007	0.0172	0.0007	0.0014	*0.4130
Yellow		*0.1168			0.0067		0.0008	*0.1243
Blue	0.0022				0.0065	0.0007	0.0094	0.0188
Black	0.0146		0.0008				0.0089	0.0243
Cyan			0.0015	0.0015	0.0167		*0.2591	*0.2788
White		0.0015	0.0008	0.0098	0.0180	*0.2239		*0.2540

*Significant at .05 level

Figure 2: Combined Confusion Probability Matrix for Eleven Color-Blind Subjects

Stimulus Color Given	Response							Overall Error Probability
	Red	Green	Yellow	Blue	Black	Cyan	White	
Red					0.0060			0.0060
Green					0.0079		0.0026	0.0105
Yellow								0.0000
Blue								0.0000
Black				0.0060			0.0060	0.0120
Cyan					0.0028			0.0028
White			0.0083		0.0165			0.0248

Figure 3: Combined Confusion Probability Matrix for Three Normal Subjects

Overall error probabilities per color in order of significance are as follows:

Green	0.4130
Cyan	0.2788
White	0.2540
Yellow	0.1243
Red	0.1113

Figure 3 reveals that none of the probabilities is significant for the normal subjects.

Questionnaire: Question 1 results are shown in Figure 4 (see the following page). Out of 20 responses made by the color-blind S as to problem colors, yellow-green, cyan-white each received 40 percent of the responses. Red-black received 20 percent of the responses. Normal subjects only mentioned that blue-black combinations were sometimes hard to see.

Question 2 results are shown in Figure 5 (see Page 11). From most preferred to least preferred color, the color-blind listed blue, black, red, yellow, white, cyan and green. Normal subjects mean preferences were higher on every color than the color-blind subjects. Their ratings were basically in the same order except for green which was rated, relatively, much higher.

Question 3 results are shown in Figure 6 (see Page 12). A majority of color-blind students felt color should be used in instruction. Some felt it was a necessity for variety while others felt it was an excellent idea isolator. However, six of the subjects answering "yes," qualified their

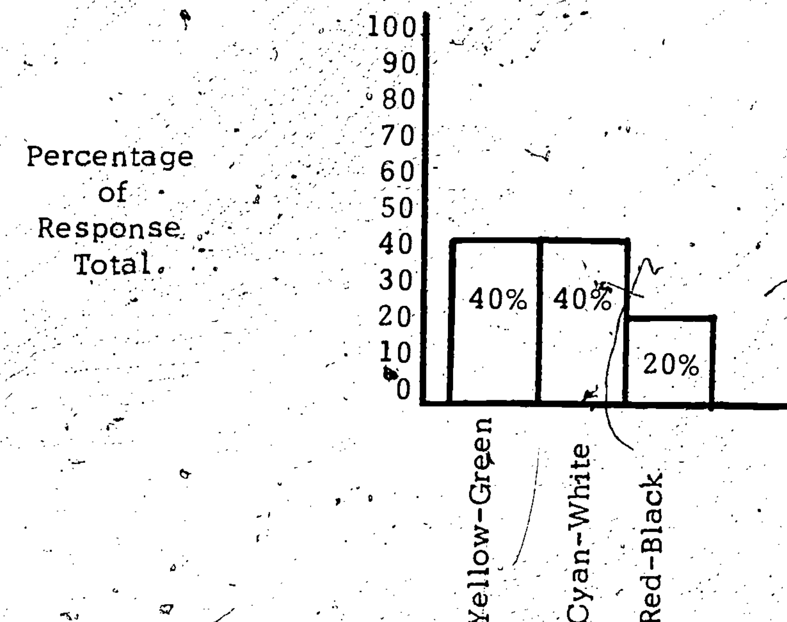

Figure 4

Problem Combinations for Color-Blind

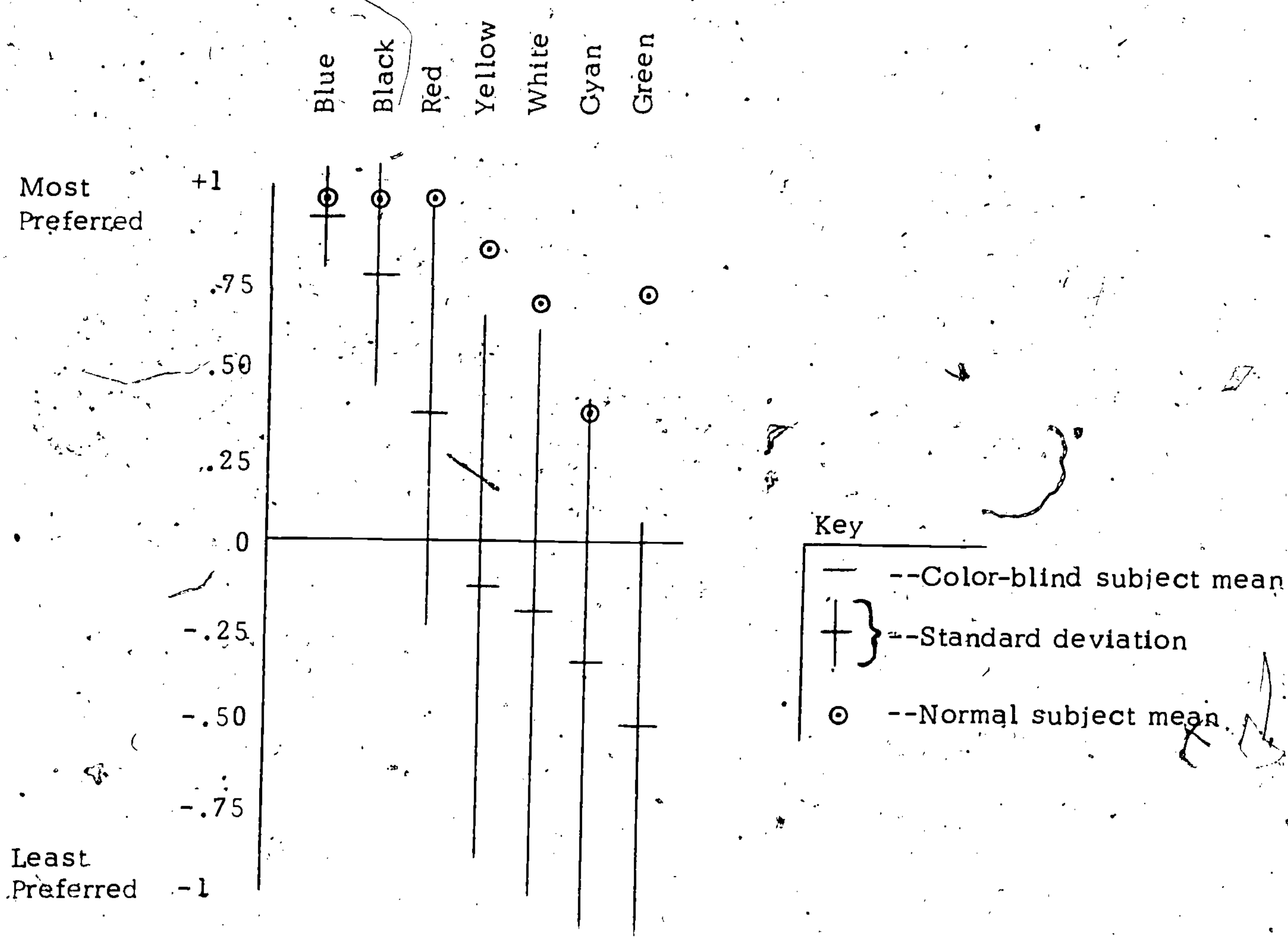

Figure 5

Preference Ratings on the TICCIT Colors

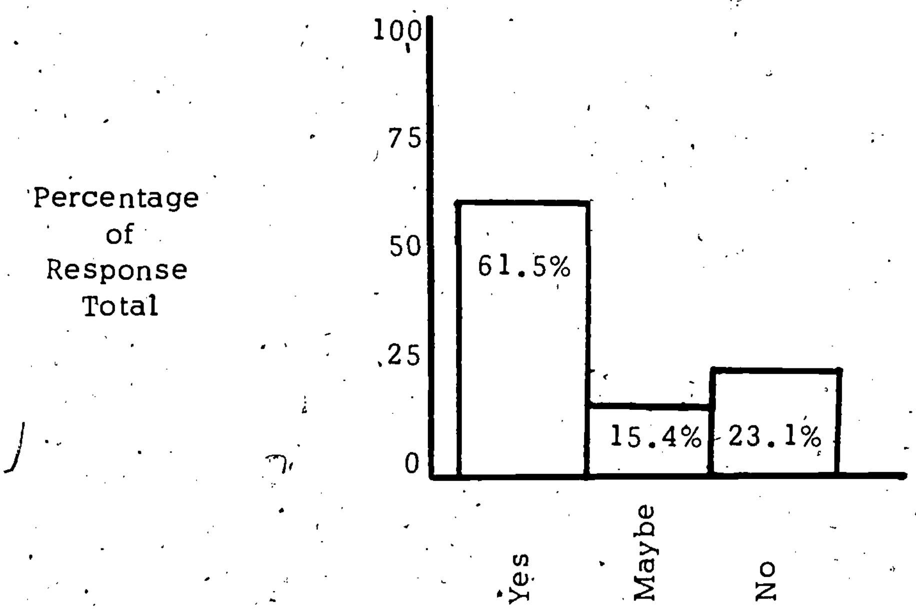

Figure 6

Response Percentages on if Color Should be Used in Instruction response with a reduction of the amount of color from the experimental stimulus material and a plea for logical use of color coding. Normal subjects all felt color was desirable.

Black and White TV, and Background Intensity: Time did not allow for more than three subjects to be asked for preference on these topics. Two of the subjects, after seeing stimulus material on both black and white and color sets, felt they liked the black and white set best. The other subject felt the color set was best because of variety. The two preferring the black and white set seemed to be judging their preference on the severely random color coded stimulus material rather than from the explained actual use of color coding in TICCIT courseware.

Two subjects preferred the medium intensity for the background on the TV display (three settings: 1) highest intensity; 2) medium intensity; and 3) lowest intensity). One preferred the highest intensity. He did say that if he worked at the terminal a while, he may tend to prefer the medium intensity.

DISCUSSION

The individual cell probabilities show that color-blind subjects experience problems discriminating between yellow and green, cyan and white, and red and black. Normal subjects have no real trouble with any of the color combinations. Most non-significant error probabilities for the color combinations may be explained in terms of errors of omission. For example, the stimulus was white, but the subject failed to mark it, leaving it blank. This failure to mark the stimulus white probably was not because of failure to discriminate between black and white, but because of overlooking the stimulus. Many errors may have also been due to not understanding the procedure completely, mismarking, etc. Had the sample size for the normal group been more equivalent to the color-blind group, the normal errors could have been used a correction factor on the color-blind errors made from carelessness rather than color confusion.

It seems rather interesting that the questionnaire revealed the same results as the error probabilities. Question 1 and 2 results seem to verify the results of the confusion matrix.

Question 3 on the questionnaire shows that the color-blind subjects generally feel that color is valuable if used logically and sparingly. This does not seem congruent with the results of the preference for the black and white TV, however.

It was not expected that the color-blind subjects would prefer the black and white TV displays to the color. Because only these subjects were asked, there is certainly a high probability of sampling bias. Question 3 shows that the color-blind subjects do tend to think color is a desirable thing on the TICCIT display. The two subjects preferring the black and white set, on further questioning indicated that the random "noisiness" of the stimulus material had made them feel that color wasn't worth it. However, both also agreed that color might be desirable if used less, and more logically. They also indicated that color that was confusable should be avoided.

A preference for the medium intensity of TV display brightness in the background was found. Time did not permit seeing if background brightness effects errors in color discrimination. None of the subjects liked the low intensity, two liked the medium intensity best, and one liked the high intensity best. All tended to feel that in working for a long time at the terminal, the medium intensity would be easiest on the eyes and enable them to discriminate colors best.

CONCLUSION

We tentatively conclude that simultaneous use of green and yellow color coding should be avoided in the TICCIT lesson material. Of course, this may not always be possible. In such cases, underlining, capitalizing, subscripting and other means of redundant cueing should be employed. White and cyan should likewise be avoided in combination, although this combination is less likely to occur in the scheme of TICCIT color usage; white is usually reserved for the characters typed on the screen by the student. The use of red and black in combination, although not as severe a problem, should be reduced where possible.

Generally, color-blind students felt that color was desirable in instruction if used sparingly and logically.

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APPENDIX

A

APPENDIX
A

PRE-TRAINING

Welcome to the BYU Institute for Computer Uses in Education. The TV--keyboard system you see before you is a computer-assisted instructional system called TICCIT. The TICCIT system allows a student to use this keyboard to command a computer to generate instruction on the TV screen. Eventually, this system, or ones similar to it, will be established in several junior colleges around the nation. Students at these colleges will have access to intermediate algebra courses and to English composition lessons on the system.

One of the highlights of this system is the use of color. This special TV screen can generate seven distinct colors for use in instruction. The high resolution screen, finer than a home TV screen, and special color intensifiers help to make the color distinct.

One question which has developed, is whether or not color-blind students might have an unduly hard, if not impossible, time distinguishing colors on the system. In some instructional displays, the information has certain color codings which help to communicate the information, and thus it is important to be able to distinguish colors, or at least intensities.

Purpose: The purpose of this study is to see what colors are most often confused with others. This will ''ow the instructional designers to avoid using confusing colors in instructional frames for the benefit of the color-blind.

Procedure: On the screen you will see seven numbered sentences. Note that each sentence is a different color, representing all of the possible seven colors. Underneath the numbered sentences, in the same order, are the names of the seven colors, color coded in that color.

On the table by the keyboard, you have six magic markers corresponding to six of the seven colors. Black is the color not represented. Each marker is also labeled in a ward as to its color to eliminate confusion.

Red	pink magic marker
Green	green magic marker
Yellow	yellow magic marker
Blue	dark blue magic marker
Black	none
Cyan	light blue magic marker
White	orange magic marker (since there is no such thing as white magic marker)

The sheets of paper on the table are xeroxed copies of the displays that will appear on the TV screen. The main difference is that the xeroxed copies are not in color, but are black on white.

For example, look at the first page marked sample. Now, push the skip button for the same display on the TV screen.

Note the amount of color on the TV display. All seven colors have been randomly assigned to each work and punctuation. Note the Red period at the end of the very last sentence. The word <u>multiple</u> in the title is also red. The in the second sentence is green. A and both in the third sentence are both yellow. And in the fourth sentence is blue. Product and powers in the fifth sentence are all black. And in the last sentence of the second paragraph is cyan, which is a light blue. The p right before this cyan colored word and is white.

The task you are asked to do, is to look carefully at the TV display and mark the corresponding xeroxed page with the magic markers to look as close to the colored TV display as possible. You have a magic marker for each color except black which you should leave like it is. Because there is no white magic marker, orange will represent white. When you are finished with that display, push the skip button and the next display will appear. Turn the page to the corresponding xeroxed display and continue to where the xeroxed page will tell you to end.

As practice, try making the first sentence of the sample display look as similar as possible to the TV display in coloring. It is probably most practical to mark over a whole word like highlighting in a book rather than trying to underline, or trace individual letters. In come cases, such as punctuation marks, there isn't much to mark so that you will have to be careful in order not to mark more than intended.

One marking strategy which may help you work faster, is to take one color at a time, and mark all words and punctuation of that color first before starting to mark with the next color. Try this strategy on the next two lines.

Any Questions? If you have any problems, just call me.. Begin.

APPENDIX

B

1. Welcome to the BYU TICCIT facility!
2. This TV display is a means to instruct.
3. Math and English will be taught.
4. Later many other subjects will be taught
5. Many questions arise about this system.
6. Can color blind students see the colors?
7. Which colors should be avoided?

Below you will find the 7 colors.

1. Red
2. Green
3. Yellow
4. Blue
5. Black
6. Cyan
7. White

RULE PAGE:1 *EDIT (-)G(s)S(----)A

Least Common Multiple(L.C.M):

The least common multiple of two natural numbers p and q is the smallest natural number which is a multiple of both p and q. The least common multiple(L.C.M) of p and q is the product of the highest powers of primes which divide p or q.

To obtain L.C.M of p and q we multiply the highest powers of primes which occur in the prime factorizations of p and q.

The L.C.M of several natural numbers is the smallest natural number which is a multiple of each of the given numbers.

It can be shown (see handbook) that

$$\cos(\alpha+\beta) = \cos\alpha \cos\beta - \sin\alpha \sin\beta$$

and

$$\cos(\alpha-\beta) = \cos\alpha \cos\beta + \sin\alpha \sin\beta$$

If we know $\cos\alpha$ or $\sin\alpha$ and α's quadrant, then we can compute the other of the two. (Remember that

$$\sin^2\alpha + \cos^2\alpha = 1$$).

This is done in Segment 2 of Lesson 6.2

So ...

FINDING HELPING WORDS IN SENTENCES

Helping words are words that sometimes join with a verb to help make a verb phrase. These helping words suggest LIKELIHOOD or POSSIBILITY. When they are used in a verb phrase, helping words always come BEFORE the verb.

As we learned before, the helping words are: may, might, must

ought (the word to usually follows ought in sentences)

shall, should

can, could

will, would

RULE PAGE:4 *EDIT (-)G(S)S(----)A

Put a comma before the added linking word if necessary.

This is it ,for That is not it.
This is it ,yet That is not it.
This is it ,so That is not it.
This is it and That is not it.
This is it or That is not it.
This is it nor That is not it.
This is it but That is not it.
This is it; That is not it.

COMMA FORYETSO

This paragraph is not coherent because it has no logical ordering.

The moment I saw the room, I was overwhelmed with a sense of disaster. The floor itself was covered with mud and debris. The piano lay broken and scratched. As my eyes moved around the room, I noticed that there were books and vases all over the floor. On the other side of the room, the windows were shuttered. In the far corner of the room, the huge chair lay overturned and spotted with mud. The entire room gave evidence of the hurricane the night before.

If Verb Phrase = 1-3 helping + verb

verb

Then the verb can end in -ing.

If Verb Phrase = + verb

Then the verb cannot end in -ing.

RULE PAGE:7 *EDIT (-)G(s)S(----)A

To find the principal n-th root $\sqrt[n]{c}$ of c, where n is odd when $c<0$, proceed as follows:

1. Find a number x such that $x^n=c$.

2. Use the following rules:

   a) If $x \geq 0$, then $\sqrt[n]{x^n} = x$.

   b) If $x<0$, then

      for even n, $\sqrt[n]{x^n} = |x|$ and

      for odd n, $\sqrt[n]{x^n} = x$.

RULE PAGE:6 *EDIT (-)G(s)S(----)A

They are the city scavengers, these pigs. Ugly brutes they are, having, for the most part, scanty brown backs, like the lids of old horsehair trunks, spotted with unwholesome black blotches. They have long, gaunt legs, too, and such peaked snouts... They are never attended upon, or fed, or driven, or caught, but are thrown upon their own resources in early life.

RULE PAGE:9 *EDIT (-)G(s)S(-----)A

"I love you"
said a great mother.
"I love you for what you are
Knowing so well what you are.
And I love you more yet, child,
deeper yet than ever, child,
for what you are going to be,
knowing so well you are going far,
knowing your great works are ahead,
ahead and beyond,
yonder and far over yet."

Carl Sandberg

RULE PAGE:10 *EDIT (-)u(s)S(----)A

"He who gets up at cockcrow and thinks of nothing except doing the good is a fellow of the Holy Shun. He who gets up at cockcrow and thinks of nothing except his profit is a fellow of the brigand Chih. Do you want to know the difference between the holy Shun and the brigand Chih? It consists of nothing else than of the difference between the good and the profitable."[1]

[1]Translated from the German text in Richard Wilhelm, Mong Dsi (Mong Ko); (Jena, 1921, Book 7a25), p. 163.

RULE PAGE:11 *EDIT (-)G(S)S(----)A

FOHN

Blinde Klage im Wind, mondene Winterage,
Kindheit, leise verhallen die Schritte an
schwarzer Hecke,
Langes Abendgelaut.
Leise kommt die weisse Nacht gezogen,

Verwandelt in purpurne Traume Schmerz und
Plage
Des steinigen Lebens,
Dass nimmer der dornige Stachel ablasse
vom verwesenden Leib.

George Trakl

OFFE PAGE:12 *EDIT (-)G(s)S(----)A

APPENDIX

C

QUESTIONNAIRE

Color Discrimination Study

1. What colors did you have trouble with?

2. Rate the seven TICCIT colors on the scales below by marking an X where appropriate.

	Most Preferred					Least Preferred
Red	+1					-1
Green	+1					-1
Yellow	+1					-1
Blue	+1					-1
Black	+1					-1
Cyan	+1					-1
White	+1					-1

3. Do you feel that color is a desirable thing to use in instruction such as the TV displays you have seen today?

APPENDIX

D

Name ____________________
Date ____________________

CONFUSION MATRIX DATA COLLECTION SHEET

Response

(Stimulus Color Given)

	RED	GREEN	YELLOW	BLUE	BLACK	CYAN	WHITE
RED							
GREEN							
YELLOW							
BLUE							
BLACK							
CYAN							
WHITE							