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TOWARD DESIGNING NEW CLASSROOMS

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This study is a work on analyzing the traditional shapes of classrooms. A model is presented that considers the rectangular classroom divided into five sections as a function of two factors: viewing distance and horizontal viewing angle. The reading time and number of errors are affected by both. This model is validated experimentally, and the shape of a trapezoid is suggested for new classrooms.

INTRODUCTION

The hypothesis made here is that the viewing distance and the viewing angle of a presented text in a classroom interact and affect the reading time and number of errors. The best viewing angle θ is 90° (straight-on) and reading performance deteriorates as the angle decreases. The characters appear legible if the stroke width of characters SW is adequate for the given viewing distance d, which may be computed from the formula (Sanders and McCormick, 1992, p.107):

$$SW = 0.0000145\ S\ d$$

where S=20 for normal acuity and the units of SW and d should be consistent. The application of θ and d on the layout of a rectangular classroom results in five different areas (I, II, III, IV, and V), as shown in Figure 1 where L represents the board width or the width of presented text.

The subareas are formed by two straight lines subtending an angle with the edges of the board and two partly drawn circumferences centered at the ends of the board with a diameter equal to a threshold viewing distance for normal acuity. It is hypothesized that subarea I is the best for reading and subarea V is the worst with respect to reading time and number of errors.

The determination of each subarea A(i), i= I, II, III, IV and V is based on θ (the viewing angle) and d (the viewing distance) as shown in Figure 1. Determination of each subarea for any size of classroom was presented by Al-Haboubi (2000). Subarea A(I) has the advantage of a larger viewing angle and a shorter viewing distance. Thus, the hypothesis made is that reading from the board is faster and more accurate from other subareas. It is further hypothesized that students sitting in A(V) experience difficulty in reading i.e., longer duration in reading and more reading errors. This lower performance is apparently attributed to a smaller viewing angle and larger viewing distance. An experiment was conducted to validate this model in the Human Factors Laboratory at King Fahad University for Petroleum and Minerals (KFUPM).

METHOD

Forty-six male students from KFUPM volunteered to participate in the experiment, which consisted of reading a three-line text projected on a screen. The students' acuity is tested at a distance of 5.8 meters from the text and at right angles (θ=90°) prior to approving their participation in the experiment. The selection of this distance depends on the stroke width measurements and will be

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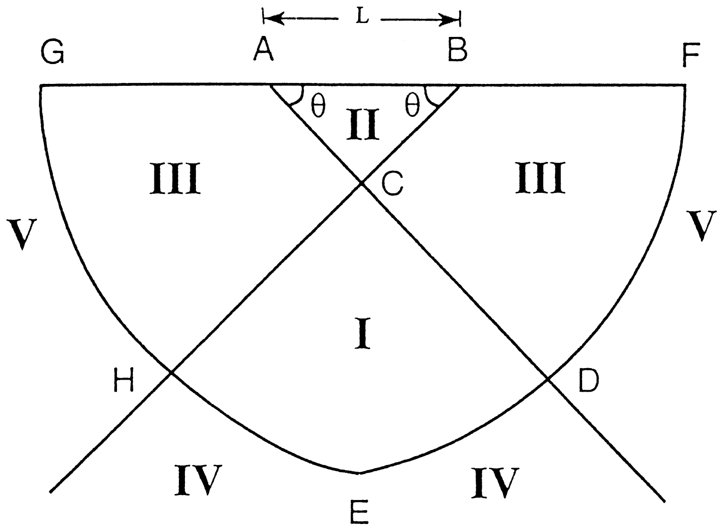

Fig. 1. Subareas of a rectangular classroom are I, II, III, IV, and V. (L: width of presented material, (: viewing angle)

shown in the results section.

Twenty-eight locations were marked on the floor with an interdistance of 1 m and the reading material occupied a width of 2 m and was 0.5 m from the first row of points, as shown in Figure 2. This setup provides testing positions at various angles and distances from the presented text. It may be noted that the layout of points shown in Figure 2 resembles the right half of a classroom, which is symmetrical to the left side. The two locations immediately in front of the screen were not tested because of the locations of the projectors.

The reading material is selected from a book written in English (Kolin, 1984), which is not a textbook at KFUPM, and discusses a topic (cycling) that is not taught in any course there. This selection eliminates the influence of background knowledge on the selected measures of performance, i.e., the reading time and number of errors. Three-line segments were photocopied across the pages of the book where 28 different transparencies were prepared. The text is projected on the screen and adjusted to cover 1 meter in width. Two identical overhead projectors were fixed at 1.5 meters from the screen (Figure 2) to project the three-line text, each at a time. The projected text from the two overhead projectors forms a width of 2 meters that represents L. The lines on each of the two projections were aligned, and the center line is adjusted at the eye height of students from the floor. This arrangement unifies the vertical viewing angle for all students. The middle point between students' eyes is aligned perpendicular to the selected point marked on the floor. This alignment was difficult for seated positions and could be done much easier while the student is standing; therefore it was adopted in the experiment. Students were instructed to stand upright, look ahead initially, and turn the head but not the shoulders toward the projected material to reduce variation in viewing distance. The illumination of the text was 900 lux where ambient lighting was provided by 27 fluorescent lamps (40 watts each) distributed over the laboratory.

The location in the laboratory (number 1 to 28), the side of the overhead exposure (left or right), and the three-line text (numbered 1 to 28) presented are each selected randomly and prepared before the subject's arrival at the laboratory. The randomization process should result in an even distribution of selected locations on the floor, selected side of overhead projection, and selected reading material. The subject would then stand in the selected position and be asked to read the presented text at a

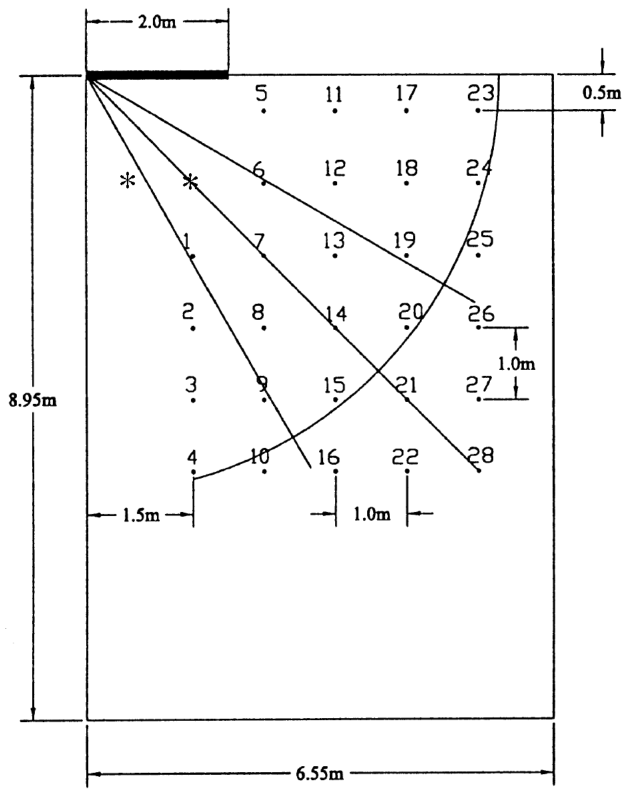

Fig. 2. Schematic diagram of the laboratory. The solid line represents the location of the presented material. Experimental locations are numbered 1 to 28 and the star symbols represent the overhead projectors. The radius of the curve is equal to 5.8m and the lines are drawn at 30, 45, and 60 degrees.

normal pace and normal voice. The time spent in reading the three-lines is measured by a stop watch to 1/100 second, and the number of errors are recorded by the experimenter. An error is counted by an examiner in the case of misreading a word or an isolated character, adding a word or a character, and omitting a word or an isolated character. After reading the text, the subject sits on a chair while the examiner prepares next trial. Each student repeats this procedure 30 times, which makes a total of 1380 trials.

RESULTS

The number of errors and time measurements of subjects for the left and right sides of presented material were pooled for each location. The number of errors was 2,033. No data were collected for location point 17 and 23, since characters were completely illegible for all subjects. Some students also had difficulty in reading from points 11, 24, 25, 26, 27, and 28. These incidents are considered as failed trials, and the rest of the 1,380 trials is 1,127, which represents the sample size in Table 1.

The results of the experiment are summarized by average values and standard deviations for reading time and reading errors (Table 1) at each location in the laboratory. It is observed that locations having a large viewing angle and that are relatively closer to the presented material, such as points 1 and 2, required less reading time and resulted in fewer errors. On the other hand, locations with sharp angles, such as point 25, or with relatively long distance, such as point 28, resulted in a

Table 1. Average and standard deviation for reading time (seconds) and number of errors at each location.

Location	Average		Standard deviation		Sample size	Failed trials
	Time	Error	Time	Error		
1	25.58	0.56	7.43	0.78	45	0
2	24.41	0.61	5.40	0.86	33	0
3	30.59	1.05	10.86	1.22	41	0
4	30.86	1.15	10.14	1.15	41	0
5	30.48	2.09	11.28	2.62	44	0
6	25.01	0.65	6.62	0.89	54	0
7	27.99	0.59	8.86	0.94	58	0
8	28.05	0.67	8.49	0.86	60	0
9	29.07	0.94	7.40	1.11	52	0
10	32.09	1.59	7.91	1.29	49	0
11	33.69	3.44	10.88	3.18	25	29
12	31.37	1.16	10.12	1.19	45	0
13	30.76	0.94	8.72	1.13	52	0
14	28.61	1.06	7.49	1.50	50	0
15	31.65	1.57	8.44	1.39	46	0
16	35.38	1.80	10.41	1.73	46	0
17	x	x	x	x	0	61
18	39.25	3.68	12.04	3.03	31	17
19	32.83	1.98	10.86	2.10	60	5
20	34.53	2.10	11.96	1.90	50	0
21	34.97	2.46	10.65	2.22	46	0
22	37.73	2.98	12.53	3.45	41	0
23	x	x	x	x	0	51
24	39.61	5.07	8.87	2.99	15	37
25	42.27	4.90	14.00	3.54	30	20
26	37.96	3.10	12.64	3.51	40	12
27	38.14	2.85	11.47	2.98	39	9
28	42.29	4.38	14.73	3.88	34	12

x: no trials at locations 17 and 23.

larger number of errors and longer reading time. An inspection of other points reveals the effect of both factors, i.e., the viewing angle and the viewing distance, on both measures of performance. A better visualization of the effect of both factors on the two measures of performance can be seen from Figures 3 and 4. Among the contour lines of the reading time (25-41 seconds), those of shorter reading times occur at larger viewing angles and shorter viewing distances. It may be observed that as the difficulty of reading increases, with smaller angles and larger distances, the contour lines become more condensed. This reflects the deterioration in reading time as a result of increasing the angles or the distance of reading, or both. A similar behavior is observed for the number of errors shown in Figure 4, where contour lines are drawn starting at 0.5 with an increment of 0.5 error.

The stroke width of presented characters averaged 1.68 mm for 30 measurements resulting in d = 5.8 meter for VA = 1 minute. The stroke height averaged 1.7 cm, making the stroke width to height ratio 1:10.

Three angles (30°, 45°, and 60°) are considered in this analysis. So the five subareas may be determined at each viewing angle as shown earlier. Points falling on the 45° line (points 7, 14, 21,and 28) belong to no subarea. A geometric representation of these subareas at each angle is done to determine the points located on the floor belonging to each subarea. The set of points allocated for

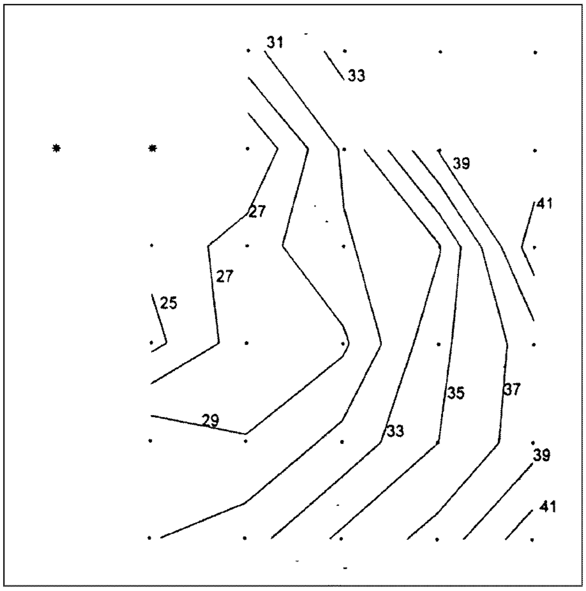

Fig. 3. Contour lines for the reading time. The numbers shown are reading times (seconds). The solid line, the dots, and the star symbols are as shown in Fig. 2.

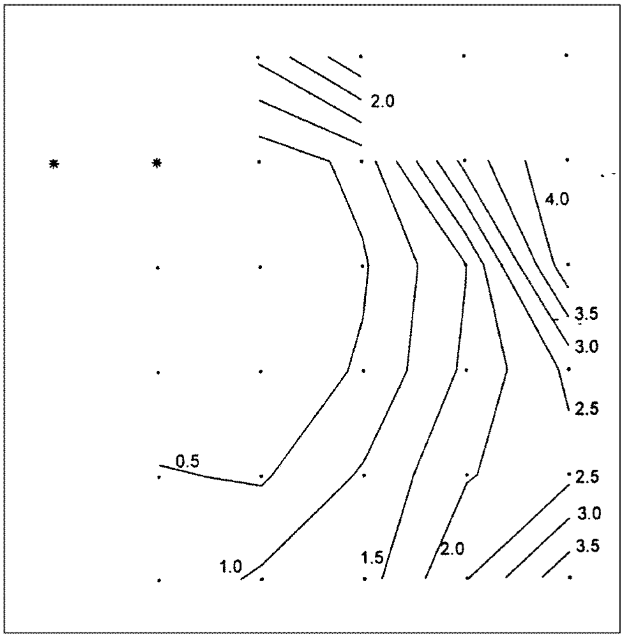

Fig. 4. Contour lines for the number of errors. The numbers shown are the number of errors. The solid line, the dots, and the star symbols are as shown in Fig. 2.

each subarea is assumed to represent that sub-area. So the collected data for reading time and number of errors is separated to reflect the performance of each subarea at each angle. The average and standard deviation for reading time and number of errors of each subarea at the three angles are

Table 2. Average reading time (seconds) and average reading error at 3 angles for each subarea.

		Average		Standard deviation		Sample size	
Angle	Subarea	Time	Error	Time	Error	Time	Error
30	I	28.96	0.98	8.62	1.26	582	582
	III	33.53	2.45	10.82	2.64	220	220
	IV	36.61	2.64	11.57	2.88	295	295
	V	42.27	4.90	13.88	3.54	30	30
45	I	28.70	0.93	8.18	1.11	318	318
	III	32.05	1.94	10.56	5.36	376	376
	IV	34.90	2.08	10.23	2.34	136	136
	V	39.21	3.50	12.64	3.42	109	109
60	I	28.96	0.95	8.31	1.11	167	167
	III	30.56	1.50	9.76	2.00	635	635
	IV	32.09	1.59	7.34	1.29	49	49
	V	38.02	3.07	12.33	3.17	276	276

Table 3. Results of ANOVA.

	Angle	Source of variables	Sum of squares	d.f.	Mean squares	*F*
Error	30	Between Groups	979.99	3	362.67	70.05
		Within Groups	5236.61	1123	4.66	
	45	Between Groups	574.65	3	191.55	40.67
		Within Groups	4404.30	935	4.71	
	60	Between Groups	628.99	3	209.67	42.14
		Within Groups	5587.61	1123	4.98	
Time	30	Between Groups	15254.54	3	5084.85	50.19
		Within Groups	113775.96	1123	101.31	
	45	Between Groups	10257.60	3	3419.20	33.88
		Within Groups	94366.22	935	100.93	
	60	Between Groups	12854.38	3	4284.79	41.42
		Within Groups	116176.11	1123	103.45	

d.f. : Degrees of freedom.

shown in Table 2.

It may be noticed that subarea II is not considered because no measurements were collected within it as a result of the locations of the overhead projectors. Considering the subarea as a single factor, a one-way analysis of variance (ANOVA) is performed for the reading time and the number of errors at each angle (30°, 45°, and 60°). The F values were highly significant as shown in Table 3. Subsequently, further pairwise statistical tests using the Least Significant Difference (LSD) method are conducted to compare the mean values among these subareas for each measure of performance at each angle using 0.05 significance level. The results of 36 LSD tests for subareas I, III, IV, and V are shown in Table 4.

DISCUSSION

The relatively large number of errors should be attributed to the difficulty of the reading task

Table 4. Summary of test results for reading time and number or errors.

		Time			Error		
Angle	Subarea	III	IV	V	III	IV	V
30	I	y	y	y	y	y	y
	III		y	y		n	y
	IV			y			y
45	I	y	y	y	y	y	y
	III		y	y		n	y
	IV			y			y
60	I	n	n	y	y	n	y
	III		n	y		n	y
	IV			y			y

y: significant difference between the means at 0.05 significance level,
n: no significant difference.

and not to English being a second language. It should be pointed out that the students can read English fluently. Besides an English education for at least six years prior to their admission to KFUPM, they spend one full year in an orientation program taking intensive courses in English. Those who pass the program are then promoted to the first year in the university. The textbooks and lectures at KFUPM are all in English, and students are not allowed to speak in Arabic in the classrooms. So the presented English text does not constitute a problem in reading. It is noted from Table 2 that the average reading time for A(I) is least among the other subareas at each of the three angles. Similarly, the least average number of errors occurs at A(I). This confirms the conjecture mentioned earlier, which classifies A(I) as the best area for students to look at the board. The average reading time increases gradually at A(III), A(IV), and A(V) respectively. The same observation applies to the average number of errors, which confirms that A(V) is the worst region in a classroom with respect to these two measures of performance. However, the experiment also reveals that A(III) is better than A(IV) at all angles. It is interesting to observe the standard deviation of reading time at A(I) to be the lowest among other subareas at all angles. This finding confirms a consistency among subjects at this subarea. It is noted from Table 4 that there is a significant difference between the average values of both measures of performance for most tests conducted at a significance level of 0.05. At a 30° angle, all pairwise tests show a significance difference in average reading time between respective subareas. This means that all subareas in the classroom are distinct from one another with respect to legibility of characters at this angle. The same may be said at the 45° angle. However, at a 60° angle, sub-reas I and III do not seem to be different statistically. This outcome is due to some favorably located points that were included in A(I) at the 45° angle being merged with the points of A(III) at 60°, which makes this subarea equivalent to A(I) at 60°. In fact, this result may be taken to decide that the 45° angle is the minimum acceptable angle (that should be adopted to classify all subareas in a classroom.

The minimum acceptable angle in this context is defined as the largest angle at which the average reading times differ significantly between I and III subareas. The definition of the minimum acceptable angle does not consider subareas IV and V, since they are beyond the normal viewing distance. A relatively large difference in reading time between these two regions at all angles exists and is statistically significant. This means that the angle effect beyond d is minimal and that the reading time cannot be improved in A(V) which confirms it as the worst subarea. Observing the results of the LSD tests under column V in Table 4 to be consistently significant at all angles for both the reading time and the number of errors clearly indicates the inferiority of this subarea. The difference in the means of reading time between A(I) and A(IV) is insignificant at the 60° angle. At both subareas, subjects seem to look at the board area with a comfortable angle. The actual indifference in reading times stems from using point 10 only in A(IV), which is just beyond the value of d. Had more positions away from the curve whose radius is d been tested, we would have noticed a significant difference.

With respect to the number of errors, the minimum acceptable angle would be 60°, since there seems to be a significant difference in average values between the I and III subareas, although the difference in average values is small, i.e., 0.55 of an error. However, with such a small error, statistical significance does not make much sense and one may consider both subareas equivalent with respect to the number of errors. It may be noted that the difference in average errors between both subareas at 45° is 1.1 error, and at 30° the difference is 1.47 error. So the average number of errors decreases as the angle increases from 30° to 60° to become practically, but not statistically, negligible. Therefore the minimum acceptable angle is 45° for both measures of performance.

An interesting observation about the results of tests conducted for the number of errors is that all tests show a significant difference between regions taken pairwise except for subareas III and IV, which consistently reveal a significant difference in the average number of errors at all three angles. Both regions are equivalent at a 30° angle with respect to the number of errors. Then as the angle increases from 30° to 60°, subarea III captures well-located points from subarea I, whereas subarea IV gets rid of badly located points to be merged to subarea V. Therefore subareas III and IV seem to be indifferent with respect to the number of errors. This trend between these two subareas occurs also with regard to the reading time, but it shows a statistical difference only at a 60° angle.

Based on this discussion, it is safe to say that the subareas of a classroom considered differ with respect to reading time and number of errors. These subareas are formed by the threshold viewing distance (d) and by a minimum viewing angle θ equal to 45°. To reduce reading difficulty, new shapes of classrooms represented by the trapezoid defined by points ABDH (Figure 1) is suggested. The suggestion is based on including subarea I. The part identified by points HDE is dropped from consideration because of the added cost involved for adding corner E and to maintain a reasonable shape, since the shape of ABDEH is quite odd.

CONCLUSION

The results confirm that subarea I is the best location in the classroom and subarea V is the worst at all three angles with respect to reading time and number of errors. Furthermore, the minimum acceptable viewing angle is determined to be 45°. With these results, it is safe to say that a "bad" spot in the classroom described by a narrow angle less than 45° and/or located farther than the visual distance would put the student at a disadvantage and most probably would make his/her learning deteriorate as measured by the number of reading errors and the duration of reading. Moreover, the results of this study encourages adopting the trapezoid as a new shape for future classrooms.

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