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Full Length Research Paper

A multifactor ANOVA study for trainees performance measurement subjected to CADCAM and CAD courses

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The study aims at investigating individual performance of trainees who are subjected to two interrelated courses, namely, CAD and CADCAM. First, a three factor design experiment has been conducted to measure the effects of trainer (A, B), trainee secondary certificate (Scientific and Industrial) and trainee college esteem (High, Low) on the mean score of CAD and CADCAM obtained by the population of trainees graduating in 2006 through 2008. Altogether, eight combinations having each eight subjects (trainees) have been considered. The second part of the study carried out investigation of 25 trainee's scores gained in CAD and CADCAM training courses by means of a 4-plot exploratory data analysis (EDA) technique. The following regression models which deal with the correlation between exam and continuing assessment scores are established and individual performances of trainees are outlined.

Key words: ANOVA, regression model, normal distribution, hypothesis testing, EDA, CAD/CAM.

INTRODUCTION

In most engineering and technical schools/colleges, CAD and CADCAM courses are proved interrelated and dependent. Both disciplines are first and foremost a creative activity which has made use of a rational decision making process. Primarily, this is governed by the satisfaction of functional requirements by means of a mechanical system. There is no unified methodology to actually design a system, much as there is no unified approach to creativity (Banares-Alcantara, 1991; Chen, 1991). Yet, some common guidelines which can be useful in a very general way (David, 2004; Hsu and Liu, 2000; Colette, 1998) as variations of the so called "design process". In the context of this course, the material given in CAD and CADCAM in technical/high schools would be better assessed and give information of how well trainees/trainers do apprehend such a matter.

In this work, the analysis of performances of trainees as well as the work still required to further enhance the training process as such are addressed using design of experiments and multivariable ANOVA tools.

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STATISTICAL BACKGROUND

Prior to undertaking this study, we shall review the basis of the ANOVA method along with the hypothesis testing and sampling distribution approach (Dudewicz, 1976; Tukey, 1977). A sample is a finite number (n) of scores. Formally, it is described using Sample statistics (that is, numbers which characterize the sample, as such). Examples of statistics are the mean $\overline{X}$, mode (M_o), median (M_d), and Standard Deviation (S_X), to cite some. Because probability models (http://www.itl.nist.gov/div898/handbook) do exist in a hypothetical world and are not easily knowledgeable, in general, an infinite number of infinitely precise scores of statistics could be considered and the resulting distribution would be a truthful probability model of the population (Tukey, 1977). Population models are characterized by parameters such as the mean μ_X and the standard deviation σ_X. Sample statistics are used as unbiased estimators (Dudewicz, 1976) of the corresponding population parameters. Hence, the mean and standard deviation of samples are estimates of the corresponding population parameters μ_X and σ_X under specific assumptions.

The sampling distribution is a "distribution of a sample statistic". It is a model of a distribution of data where data are "statistics" rather than "raw scores". The sampling distribution of the mean is a special case of distribution of sample means which is described using parameters $\mu_{\bar{X}}$ and $\sigma_{\bar{X}}$. These parameters are closely related to the parameters of the population distribution. Also, the relationship being expressed by the Central Limit Theorem (CLT) stipulates that the mean of the sampling distribution of the mean ($\mu_{\bar{X}}$) equals to the mean of the population (μ_X), and the standard error of the mean ($\sigma_{\bar{X}}$) equals to the standard deviation of the population (σ_X) divided by the square root of the sample size (n). This is under the assumption of populations being normal or having large size (> 30).

$$\mu_{\bar{X}} = \mu_X \text{ and } \sigma_{\bar{X}} = \frac{\sigma_X}{\sqrt{n}}$$

Finally, given a confidence interval (CI), the F-ratio is calculated to validate/reject the null hypothesis that is presupposed *a priori* by the experimenter. Note that, the shape of the F-distribution depends on the sample drawn and groups size which means the degree of freedom of MSB and MSE referenced later in this paper. The type I error (α = 0.01, 0.05 or 0.1) is also relevant to the F-distribution shape.

Estimation of the population parameter (σ_X)

In countless situations, it is proved unpractical to measure population means straightforwardly. The Analysis of variance (ANOVA), which is commonly used to test out differences among population means, has revealed useful to answer such a query. The ANOVA approach works under the following assumptions (Tukey, 1977): 1) homogeneity of populations variances (sometimes referred to as sphericity), 2) populations need be normally distributed or make use of the C.L.T. provided *n is large*, 3) and, finally, each subject is experimented once which means that each value is sampled independently from each other value. Likewise, the ANOVA test is based on two independent estimates of the population variance (σ_X), namely, the Between and the Within estimates:

(i) Mean square error estimate (MS_{within}): Since each of the sample variances may be considered as independent estimate of the population variance (σ_X^2), finding the mean of the variances provides a way of combining separate estimates of σ_X^2 into a single value. The resulting statistic is termed Mean Square Within (MS_{within}). The MS_{within} estimates the population variance (σ^2) regardless of whether the null hypothesis *(H_0: $\mu_1 = \mu_2 = ... = \mu_k$)* is true.

(ii) Mean Square Between estimate ($MS_{Between}$): here, the population variance (σ_X^2) estimate is based on differences among the sample means and under the null hypothesis *(H_0: $\mu_1 = \mu_2 = .. = \mu_k$)*, rigorously. Otherwise, $MS_{Between}$ would estimate a quantity larger/lesser than σ_X^2. The $MS_{Between}$ makes use of the concept of the *sampling distribution* and the *C.L.T.*

The F-ratio of $MS_{Between}$ over MS_{within} is calculated so that the difference between the means relatively to the variability within each sample is measured. The larger this value, the greater the likelihood that the differences between the means are due to factors other than chance, solely (that is, existence of real effects). In an ANOVA, the F-ratio is the statistic used to test the hypothesis that the effects are real which means that the means are significantly different from one another. The following are key synopsis:

(a) $MS_{Within} = \frac{1}{k}\sum_{i=1}^{k} s_i^2$ where, k: number of samples,

(b) $MS_{Between} = n\,\sigma_{\bar{X}}^2$ where, k: sample size and the total variance: $MS_{total} = MS_{Within} + MS_{Between}$,

(c) Under the null hypothesis MS_{Within} and $MS_{Between}$ are about the same, otherwise (that is, assuming the alternative hypothesis), MS_{Within} still estimates σ_X^2 because differences in population means do not affect variations, but this does not apply for $MS_{Between}$,

(d) Use F-ratio to corroborate the incidence of real effects in conjunction with random errors (http://www.itl.nist.gov/div898/handbook).

Two strategic experimental designs have been argued prior conducting this study: Within-subjects and Between-subjects ANOVA. Within-subjects ANOVA, also known under repeated measures factors appellation (Dudewicz, 1976), involves comparison of the same subjects under different condition (levels). Each subject's performance is measured at each level of a given factor. In between-subjects ANOVA each subject's performance is measured only once and the comparisons are between different groups of subjects, instead.

STUDY EXPERIMENTAL DESIGN

The study has been conducted at the production section of the Mechanical Technology Department at Jeddah College of Technology (Saudi Arabia). It has apprehended the population of trainees graduating in 2006, 2007 and 2008. Since our population of trainees is already split into groups, accordingly, a stratified sampling strategy has been adopted. The study is concerned by:

Table 1. Multifactor ANOVA data.

Trainer	College esteem			
	High		Low	
	Secondary certificate		Secondary certificate	
	Scientific	Industrial	Scientific	Industrial
Trainer_A	94	86	97	66
	98	99	98	82
	91	90	78	88
	72	87	90	86
	90	97	98	93
	95	84	77	65
	88	98	81	74
	65	71	84	76
Trainer_B	72	70	78	64
	89	76	82	70
	77	90	68	76
	88	80	87	83
	90	94	75	66
	67	70	78	65
	60	99	60	62
	89	60	74	76

(i) Studying the effects of three independent factors, namely, trainer (A, B), trainee secondary certificate (Scientific, Industrial) and trainee college esteem (High, Low) on a response (dependent factor) which measure the mean score of CAD and CADCAM obtained by the population of trainees graduating in 2006 through 2008. The mean score of CAD and CADCAM is calculated by averaging the final scores obtained in CAD and CADACAM. 64 graduated trainees are randomly selected and eight trainer/trainee secondary certificate/college esteem combinations are formed. Table 1 gives the data of the ANOVA study.

(ii) Part 2 considered a sample of 25 graduated trainees in 2005, 2006 and 2007 for whom both the Exam and Continuing Assessment scores obtained in CAD and CADCAM are recorded. The Final Score for each trainee is calculated by summing the Exam and the Continuing Assessment scores. Table 2 gives the scores obtained by each of the 25 trainees.

RESULTS

Multifactor ANOVA study findings

The ANOVA summary table shown in Table 3 shows both the Trainer and Secondary Certificate factors has statistically significant effect on the mean score of CAD and CADCAM at the 95.0% confidence level. This is because both associated p-values are less than 0.05 (the significance level chosen for the whole study). However, no interaction does exist since no p-values is less than 0.05 and the interaction plot shows two almost parallel lines. Consequently, we conclude that the statistical test for interaction is not significant at 95.0%. The forms of the interaction are shown in Figure 1.

Data analysis and regression prediction model

In part 2 of this study, with regard to CAD and CADCAM training courses for the 25 graduating trainees as it has been initiated earlier, we search for how do Exam scores vary with the Continuing assessment scores. Next, we seek out a regression model of the CADCAM_Final scores on *the* CAD_Final scores. A 4-plot technique is used for EDA (http://www.itl.nist.gov/div898/handbook) and Figure 2 through 8 give statistical analyses of data collected for the six variables as summarized in Table 2.

Data analysis of the CAD scores

The 4-plots technique includes: 1) a run sequence plot (upper-left), 2) a lag plot (upper-right), 3) a histogram (lower-left), and, 4) finally, a normal probability plot (lower-right). The plots are worked out using Statgraphics Plus®. Primarily, the 4-plots technique tests whether collected scores have a fixed location, fixed variation, are random and whether they emanate from a normal/approximately normal distribution. Moreover, the technique helps infer outliers.

Data analysis of the CAD_continuing assessment scores shows, according to the two upper plots (Figure 2), the process has an approximately fixed location and

Table 2. Trainees scores records in CAD and CADCAM.

#	CAD			CADCAM		
	CAD_Cont.Ass. Score (/60)	**CAD_Exam Score (/40)**	**CAD_Final Score (/100)**	**CADCAM_Cont.Ass. Score (/60)**	**CADCAM_Exam Score (/40)**	**CADCAM_Final Score (/100)**
1	45	36	81	55	25	80
2	57	39	96	53	37	80
3	55	38	93	38	33	71
4	58	40	98	53	32	85
5	46	36	82	42	28	70
6	58	39	97	61	39	100
7	57	38	95	39	24	63
8	45	15	60	34	15	49
9	32	28	60	43	29	72
10	48	20	68	55	30	85
11	33	27	60	41	30	71
12	38	25	63	49	29	78
13	59	36	95	40	34	74
14	42	38	80	45	24	69
15	36	24	60	46	27	73
16	44	36	80	55	38	93
17	42	38	80	46	37	83
18	38	25	63	45	28	73
19	35	37	72	43	34	77
20	49	34	83	50	35	85
21	51	40	91	55	38	93
22	53	12	65	40	20	60
23	58	38	96	60	40	100
24	40	31	71	47	33	80
25	44	36	80	41	32	73

Table 3. Multi-factor ANOVA for Mean CAD and CADCAM scores.

Source	Sum of squares	Df	Mean square	F-Ratio	P-value
Main effects					
A: Trainer	1434.52	1	1434.52	13.43	0.0006
B: Secondary certificate	500.641	1	500.641	4.69	0.0346
C: College esteem	118.266	1	118.266	1.11	0.2972
Interactions					
AB	19.1406	1	19.1406	0.18	0.6736
AC	6.89063	1	6.89063	0.06	0.8004
BC	301.891	1	301.891	2.83	0.0983
ABC	31.6406	1	31.6406	0.30	0.5884

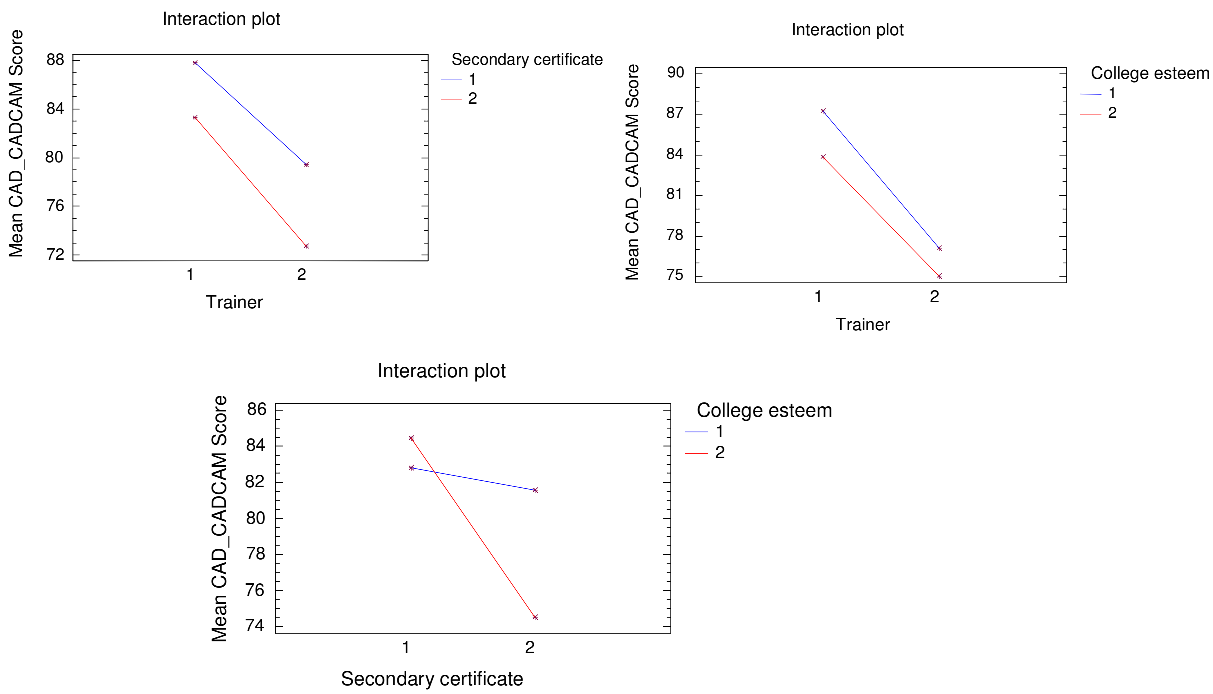

Figure 1. Main effects and interaction plots of the multi-factor ANOVA study.

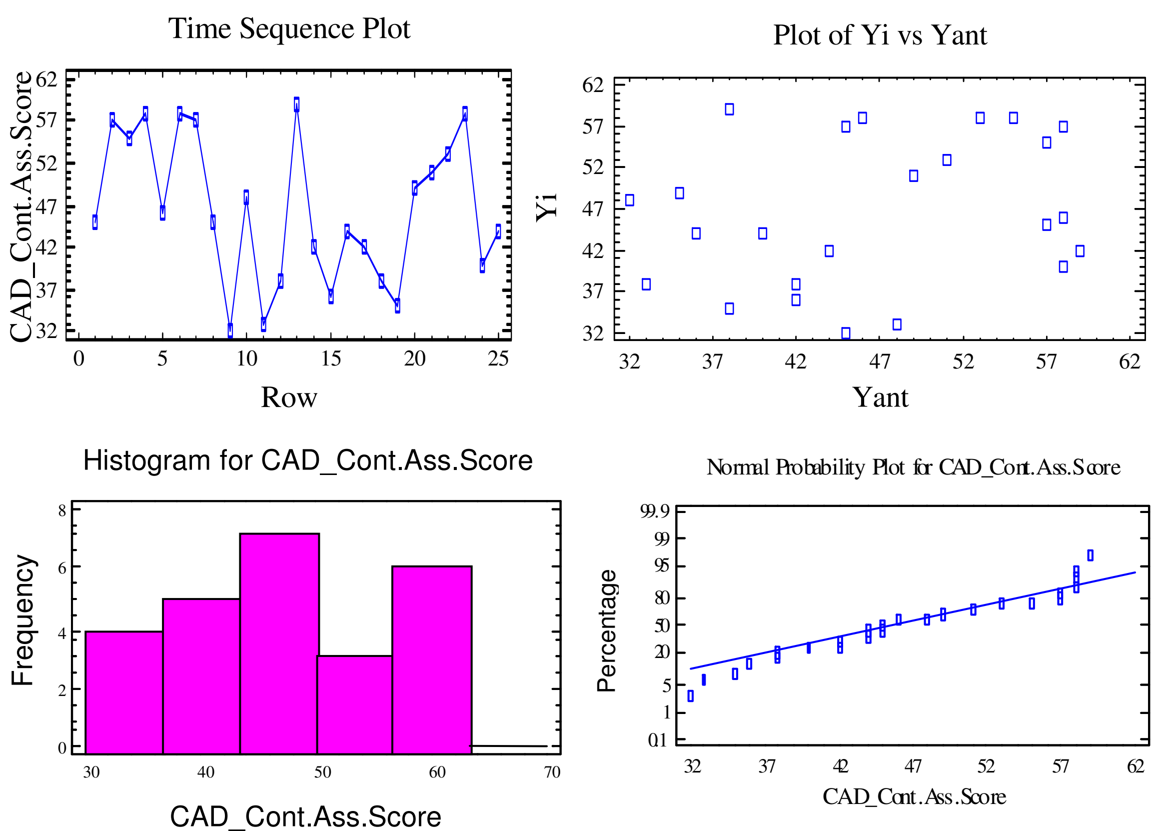

Figure 2. EDA for the CAD continuing assessment scores.

Table 4. Summarized statistics for CAD_Cont. Ass. scores.

Summarized statistics for CAD_Cont.Ass.Score		Confidence intervals for CAD_Cont.Ass. Scores
Count = 25	Range = 27.0	95.0% confidence interval for mean:
Average = 46.52	Skewness = -0.0131955	46.52 +/- 3.57105 (42.949; 50.091)
Variance = 74.8433	Kurtosis = -1.22816	
Standard deviation = 8.6512	Stnd. skewness = -0.0269353	95.0% confidence interval for standard deviation:
Standard error = 1.73024	Stnd. kurtosis = -1.25348	(6.75511;12.0351)
Minimum = 32.0	Coeff. of variation = 18.5967%	
Maximum = 59.0		

variation and data are random (the lag plot do not show any special pattern). The normal probability plot (lower-right) and the values of the *Stnd.* Kurtosis and Stnd. Skewness (Table 4) confirm that data emanate from an approximately normal distribution.

Data Analysis of the CAD_Exam scores shows that, the time sequence plot is not flat (Figure 3) which means shift in location and variation (here, around row 8 and 23). Data show no special pattern (proof of randomness) and they are likely coming from a non normal distribution since the values of Stnd Skewness is out of range [-2, 2] (Table 5). This is better expressed by the shape of the normal probability plot. A correction of non normality is carried out using Box-Cox transformation so that variance of the series is further stabilized and the probability distribution of newly generated data would stick to normality. The current transformation takes the following form as reported by Statgraphics Plus®:

$$1+\frac{(CAD\_Exam\,Score)^{2.09547}}{3.09547 * 30.956^{2.09547}}$$

The regression linear model (Ryan Thoman, 1997) of the CAD_Exam scores on the CAD_Continuing Assessment scores are shown in Figure 4. Using Statgraphics Plus®, and considering the dependent variable CAD_Exam score and CAD_Cont. Ass. score as independent, we find out the linear regression model as shown in Table 6.

Since the p-value in the ANOVA table is superior to 0.05, we argue that statistically there exists no significant relationship between CAD_Exam Scores and CAD_Cont. Ass. scores at the 95.0% confidence level. Also, when compared with alternative regression models, the linear regression model seems to be the most appropriate in terms of correlation and R-Squared as shown in Table 7. The R-Squared statistic indicates that the model as fitted explains only 12.6206% of the variability in CAD_Exam Scores. The correlation coefficient equals 0.355255 and indicates a relatively weak relationship between the variables. In addition, both predicted and observed scores show severe discrepancy with outliers (Std. error of residuals shown in Figure 4, right plot).

Data analysis of the CADCAM scores

The same preceding steps are applied for analyzing CADCAM scores. According to the two upper plots shown in Figure 5, the process of the CADCAM_ Continuing Assessment shows an approximately fixed location and variation. Data are random (i.e., no special pattern in the lag plot) and do emanate from an approximately normal distribution as revealed by the normal probability plot and the values of the Stnd. Kurtosis and Stnd. Skewness (Table 8).

For the EDA CADCAM_Exam plots, the time sequence plot is approximately flat, however, there exists shift in location around row 7 (Figure 6). Data are scattered showing no special pattern (proof of randomness) and they are likely coming from a normal distribution with regard to the normal probability plot and the Stnd Skewness and Stnd Kurtosis values which are located within [-2, 2].

The regression model of the CADCAM_Exam on the CADCAM_Continuing Assessment scores is shown in Figure 7. Using Statgraphics Plus®, we find out the linear regression as described in Table 9 and 10. Compared with alternative regression models, the S-curve regression fit is by far the best to express data in terms of correlation and R-Squared (Table 11). Because the p-value in the ANOVA table is less than 0.05, there exists statistically significant relationship between CADCAM_Exam Scores and the CADCAM_Cont. Ass. scores at the 95.0% confidence level. The R-Squared statistic indicates that the S-curve model, as fitted, explains 38.6539% of the variability in CADCAM_Exam Scores and the correlation coefficient equals 0.631723, indicating moderate relationship between the variables. Predicted and observed scores show discrepancy as it is elucidated in Figure 7.

Regression model of the CADCAM_Final on CAD_Final scores

At present, we purpose to investigate regression models of the CADCAM_Final scores on the CAD_Final scores as they are recognized as interrelated courses. Figure 8 shows the plot of the fitted model. Using Statgraphics Plus®, we compute the regression model and the associated ANOVA table (Table 12). Compared with

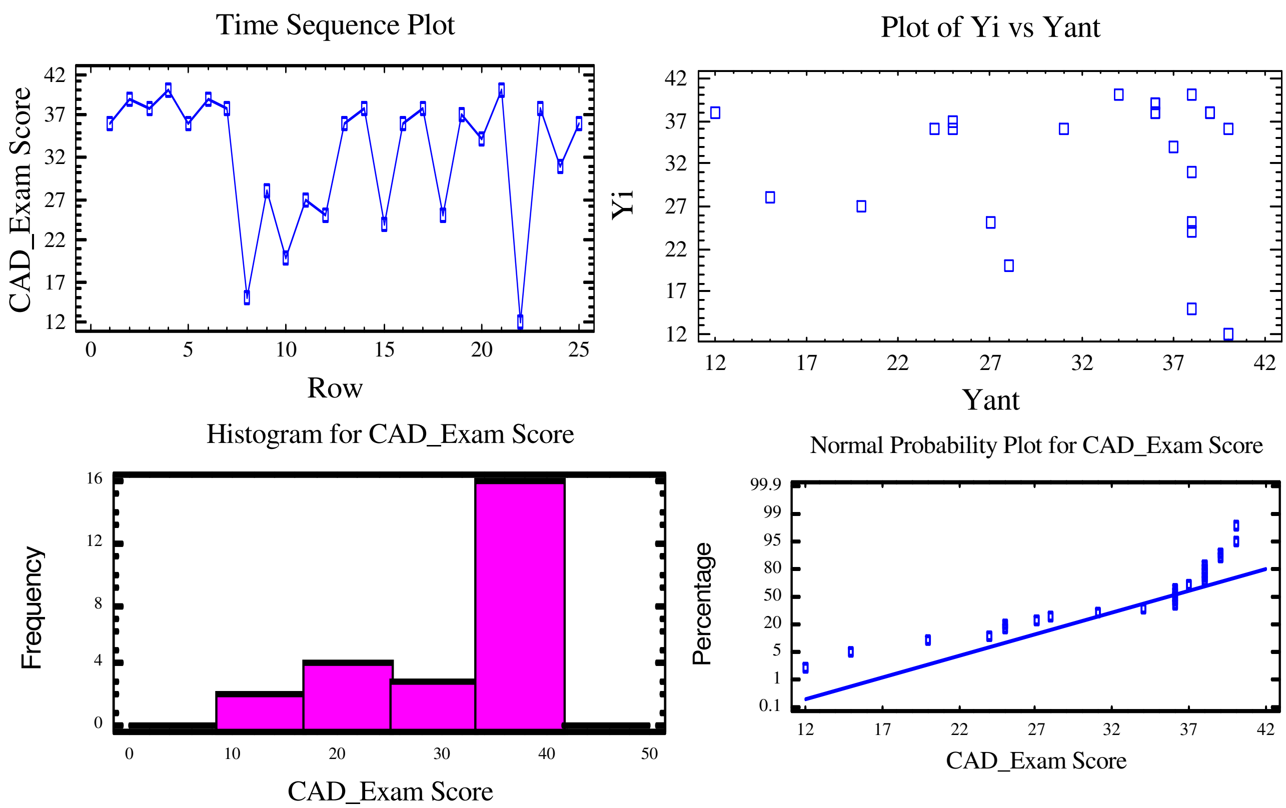

Figure 3. EDA for CAD_Exam scores.

Table 5. Summarized statistics for CAD_Exam Scores.

Summarized statistics for CAD_Exam Scores		Confidence intervals for CAD_Exam Scores
Count = 25	Maximum = 40.0	95.0% confidence interval for mean:
Average = 32.24	Range = 28.0	32.24 +/- 3.31786 (28.9221; 35.5579)
Variance = 64.6067	Skewness = -1.21251	
Standard deviation = 8.0378	Kurtosis = 0.537642	95.0% confidence interval for standard deviation:
Standard error = 1.60757	Stnd. skewness = -2.47503	(6.27616; 11.1818)
Minimum = 12.0	Stnd. kurtosis = 0.548729	
	Coeff. of variation = 24.9312%	

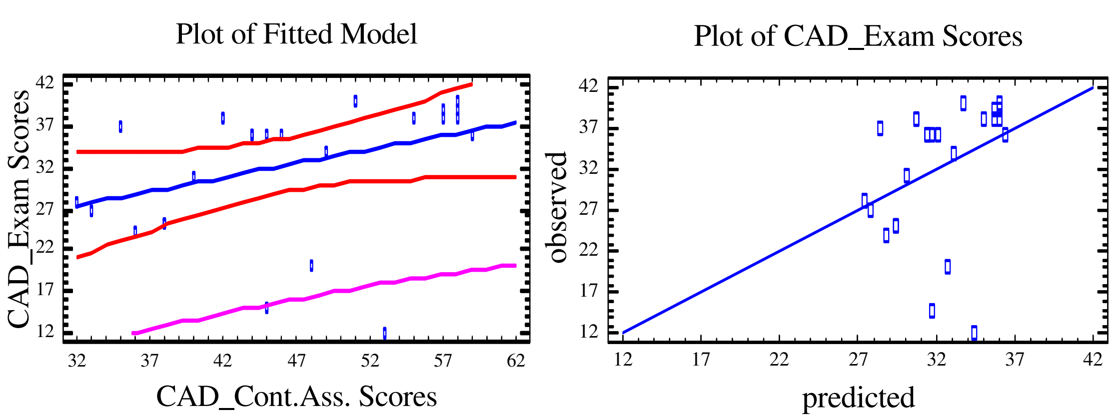

Figure 4. Regression model (CAD_Exam on CAD_Continuing Assessment).

Table 6. Linear regression model of the *CAD_Exam scores* on the *CAD_*Continuing Assessment scores.

Linear regression model				
CAD_Exam Scores = 16.8853 + 0.330067*CAD_Cont.Ass.Scores				
		Standard	**T**	
Parameter	**Estimate**	**Error**	**Statistic**	**P-value**
Intercept	16.8853	8.56317	1.97185	0.0608
Slope	0.330067	0.181093	1.82264	0.0814

Analysis of variance

Source	Sum of squares	Df	Mean square	F-Ratio	P-value
Model	195.69	1	195.69	3.32	0.0814
Residual	1354.87	23	58.9074		
Total (Corr.)	1550.56	24			

Correlation coefficient = 0.355255, R-squared = 12.6206 percent, Standard error of Est. = 7.67511.

Table 7. Comparison of alternative regression models.

Model	Correlation	R-squared (%)
Linear	0.3553	12.62
Square root-X	0.3507	12.30
Logarithmic-X	0.3458	11.96
Reciprocal-X	-0.3349	11.21
Square root-Y	0.3054	9.32
Exponential	0.2508	6.29
Multiplicative	0.2393	5.73
S-curve	-0.2272	5.16
Reciprocal-Y	-0.1368	1.87
Double reciprocal	0.1110	1.23
Logistic	<no fit>	
Log probit	<no fit>	

alternative regression models, the S-curved model demonstrates superior stick to data in terms of correlation and R-Squared. Besides, because the p-value in the ANOVA table is less than 0.05, there exists a statistically significant relationship between CADCAM_Final scores and the CAD_Final scores at 95.0% confidence level. The R-Squared statistic indicates that the model as fitted explains 22.8615% of the variability in CADCAM_Final score and the correlation coefficient equals 0.478137 which indicates a relatively week relationship between the variables. Predicted and observed scores show discrepancy (Figure 8).

INDIVIDUAL PERFORMANCES OF TRAINEES

Lastly, we inquire about individual performances of the 25 subjects sampled randomly from the population of trainees. Each subject is performed twice and has consequently two final scores, namely, CAD and CADCAM score. In that way, each trainee performance is measured at each of the two levels of the factor *"Course"*. Using Statgraphics Plus®, the ANOVA F-test will investigate whether there are any statistically significant differences between the means (average of the CAD and CADCAM score). If so, the Multiple Range Tests are applied to discriminate which means are statistically significantly different from which other. From Figure 9 and Table 13 we conclude:

(i) No outliers as Kruskal-Wallis test (Anscombe and Tukey, 1963; Douglas,2004) gives a p-value (Test statistic = 35.5583 and p value = 0.0605402) greater than or equal to 0.05. Statistically speaking, there exists no significant difference amongst the medians at 95.0% confidence level.

(ii) Difference between the smallest standard deviation and the largest (from 1 - 3) do infringe the 'equal

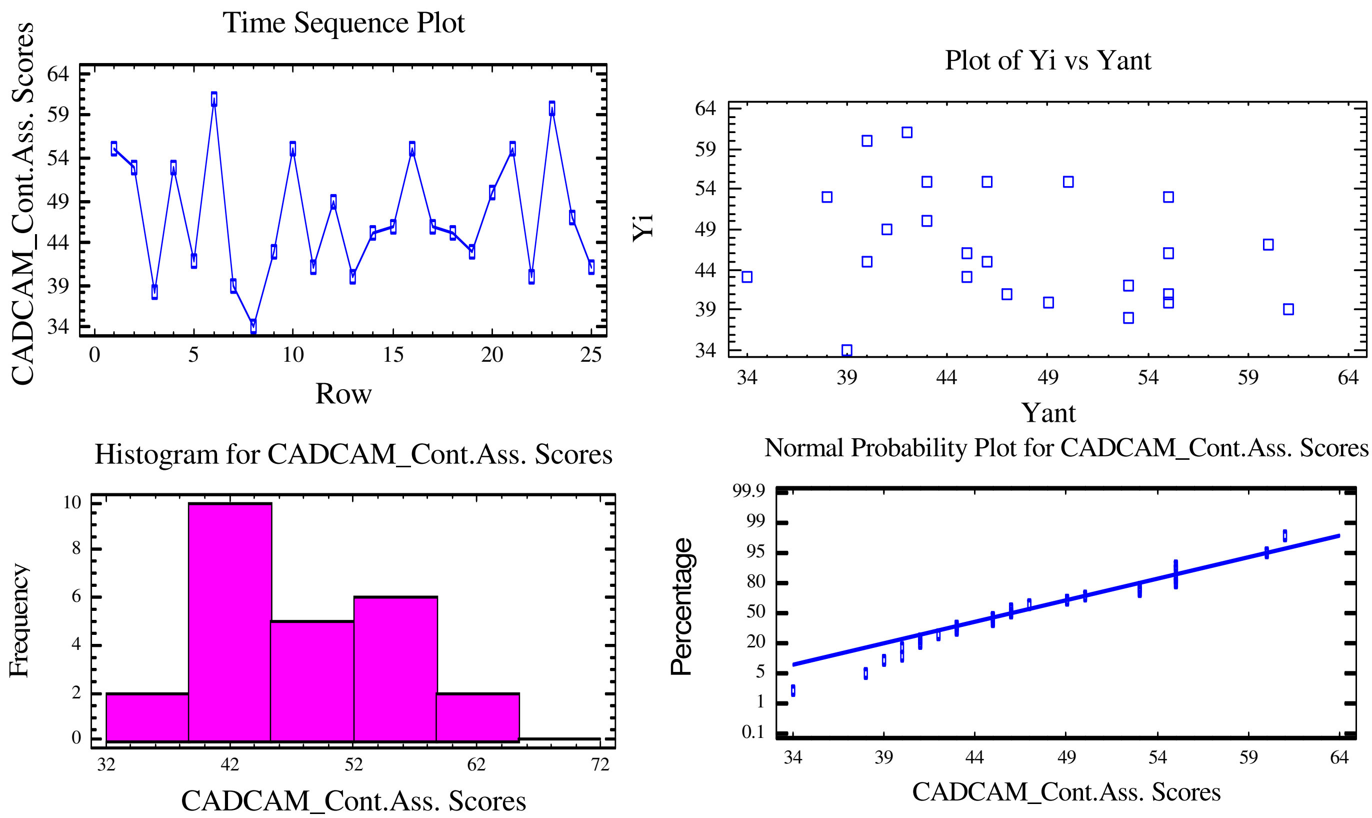

Figure 5. E.D.A. for *CADCAM_Continuing Assessment* scores.

Table 8. Summary statistics for CADCAM_Cont. Ass. Scores

Summary Statistics for CADCAM_Cont.Ass. Scores		**Confidence Intervals for CADCAM_Cont.Ass. Scores**
Count = 25	Range = 27.0	95.0% confidence interval for mean:
Average = 47.04	Skewness = 0.296118	47.04 +/- 2.98727 (44.0527;50.0273)
Variance = 52.3733	Kurtosis = -0.811466	95.0% confidence interval for standard deviation: (5.65081;10.0677)
Standard deviation = 7.2369	Stnd. kurtosis = -0.828199	
Minimum = 34.0	Stnd. skewness = 0.604449	
Maximum = 61.0	Coeff. of variation = 15.3847%	

variance' hypothesis set forth with regard to ANOVA test Cochran's C test: 0.24381, p-value = 0.258976, Bartlett's test: 2.53789 p-Value = 0.836052, Hartley's test: 1024.0. Since the smaller of the p-values (0.258976) is greater than or equal to 0.05, there is not a statistically significant difference amongst the standard deviations at 95.0% confidence level.

(iii) Because the p-value of the F-test is less than 0.05 (Table 14), there exists no statistically significant individual differences between the mean Trainee_Final_Score (mean of CAD and CADCAM scores) from one level of factor to another at the 95.0% C.L. The method currently being used to discriminate among the means is Fisher's Least Significant Difference (L.S.D.) procedure.

Concluding remarks

The study has been conducted in two stages: 1) study of main and interaction effects on population of trainees score subjected to two interrelated courses CAD and CADCAM, namely, and 2) analysis of data collected and regression models. Many points have been addressed and conclusions drawn. These are briefly summarized in Table 15 and 16. With regard to the population of trainees graduating in 2006 through 2008, the study has shown that:

(i) Trainer and type of trainee certificate factors have significant effects on the average score obtained in CAD and CADCAM final score at 95.0%,
(ii) Both in CAD and CADCAM, the variation in scores

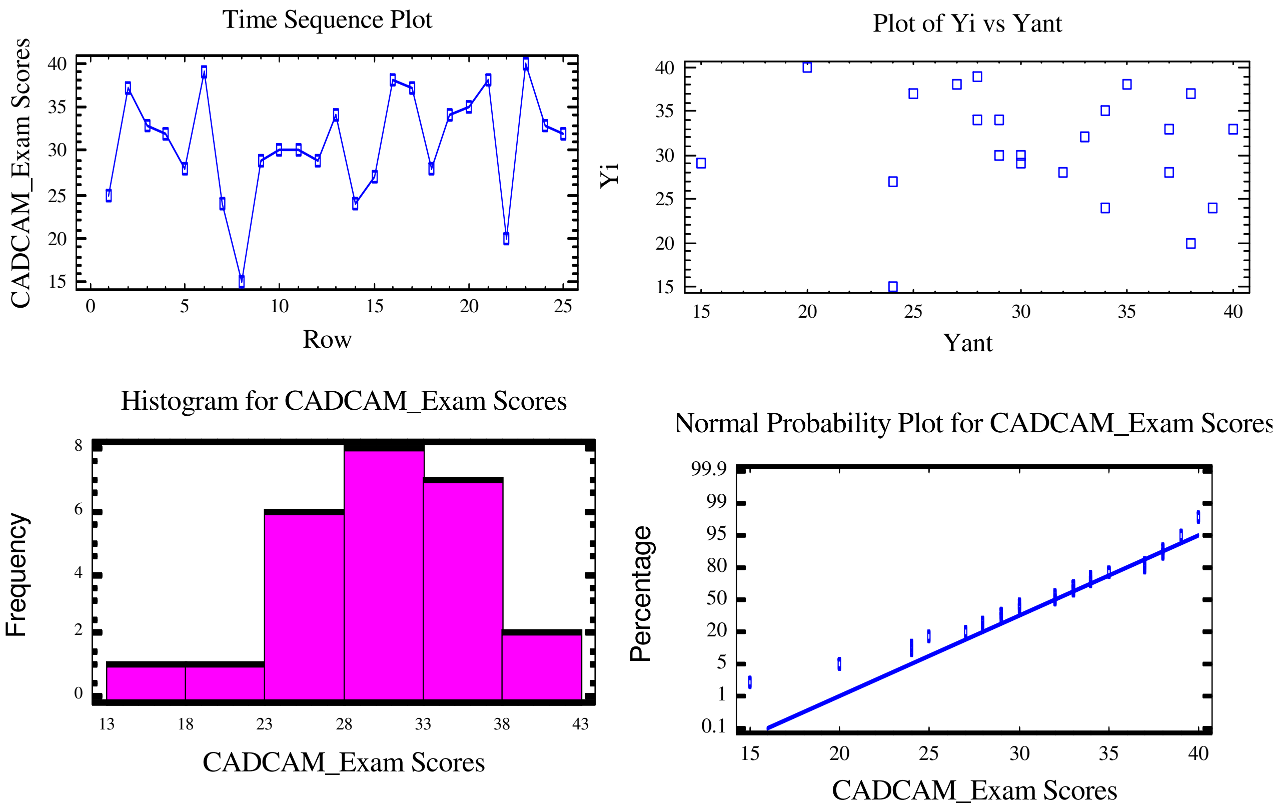

Figure 6. E.D.A. for CADCAM_Exam scores.

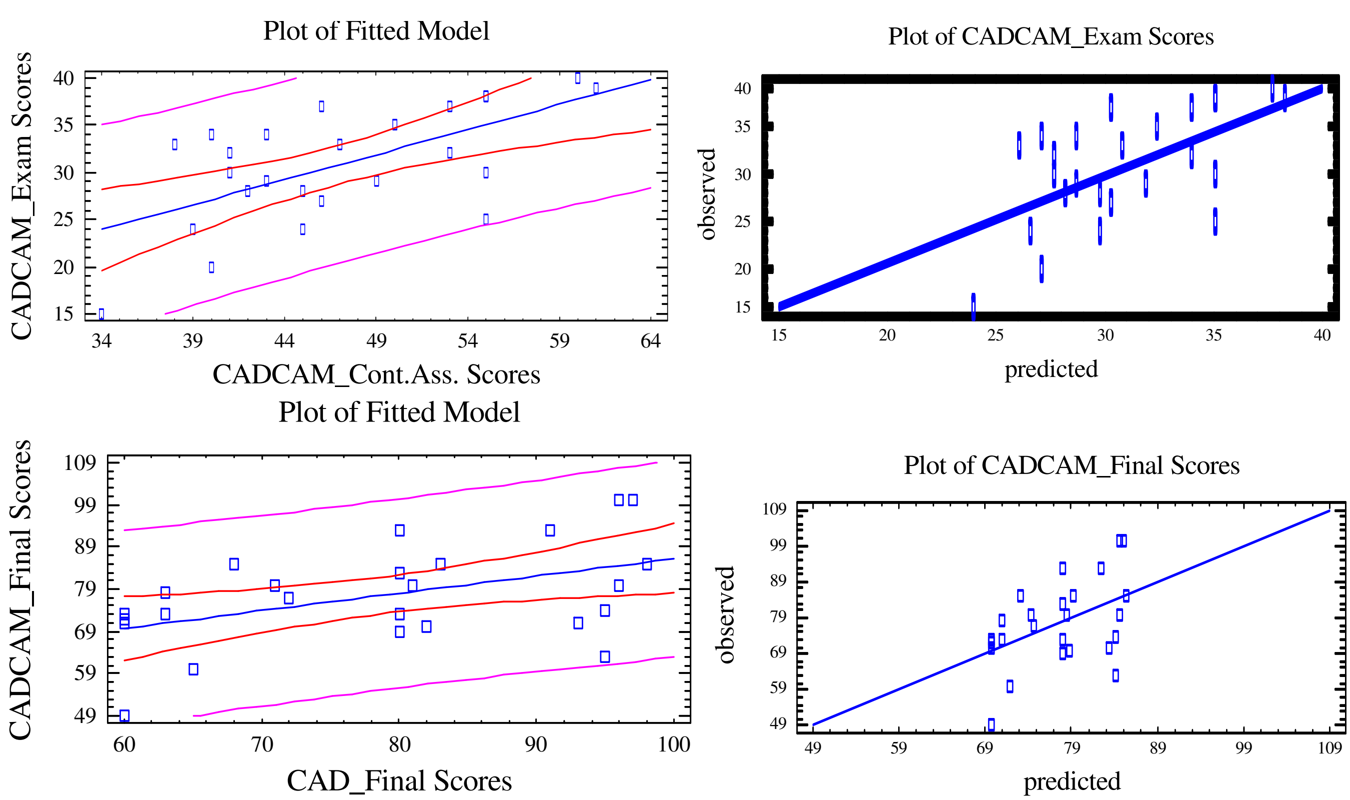

Figure 7. Regression model (CADCAM_Exam on CADCAM_Assessment).

Table 9. Summarized statistics for CADCAM_Exam Scores.

Summary statistics for CADCAM_Exam Scores		Confidence intervals for CADCAM_Exam Scores
Count = 25	Range = 25.0	95.0% confidence interval for mean:
Average = 30.84	Skewness = -0.681259	30.84 +/- 2.54645 (28.2936;33.3864)
Variance = 38.0567	Kurtosis = 0.385194	95.0% confidence interval for standard deviation:
Standard deviation = 6.16901	Skewness = -0.681259	(4.81694;8.58203)
	Stnd. kurtosis = 0.393137	
Standard error = 1.2338	Stnd. skewness = -1.39061	
Minimum = 15.0	Coeff. of variation = 20.0033%	
Maximum = 40.0		

Table 10. Linear regression model of the *CADCAM_Exam scores* on the *CADCAM_Continuing Assessment* scores.

Linear regression model

CADCAM_Exam Scores = 5.90988 + 0.529977*CADCAM_Cont.Ass. Scores

Parameter	Estimate	Standard Error	T Statistic	P-value
Intercept	5.90988	6.62271	0.892365	0.3814
Slope	0.529977	0.139216	3.80686	0.0009

Analysis of variance

Source	Sum of squares	Df	Mean square	F-Ratio	P-value
Model	353.05	1	353.05	14.49	0.0009
Residual	560.31	23	24.3613		
Total (Corr.)	913.36	24			

Correlation coefficient = 0.621723,
R-squared = 38.6539%,
Standard error of Est. = 4.93572.

Table 11. Comparison of alternative regression models.

Model	Correlation	R-squared (%)
S-curve	-0.6399	40.95
Reciprocal-X	-0.6392	40.86
Double reciprocal	0.6321	39.96
Logarithmic-X	0.6310	39.81
Square root-X	0.6264	39.24
Linear	0.6217	38.65
Multiplicative	0.6216	38.64
Square root-Y	0.6134	37.63
Exponential	0.6032	36.38
Reciprocal-Y	-0.5760	33.18
Logistic	<no fit>	

obtained in exams is weekly correlated with that obtained during continuous assessment. Yet, it is superior in CADCAM,

(iii) The correlation between CAD and CADCAM final score is moderately strong,

(iv) Most regression models have shown discrepancy between observed and predicted values as it is pointed out by the residual values, especially, with CAD course.

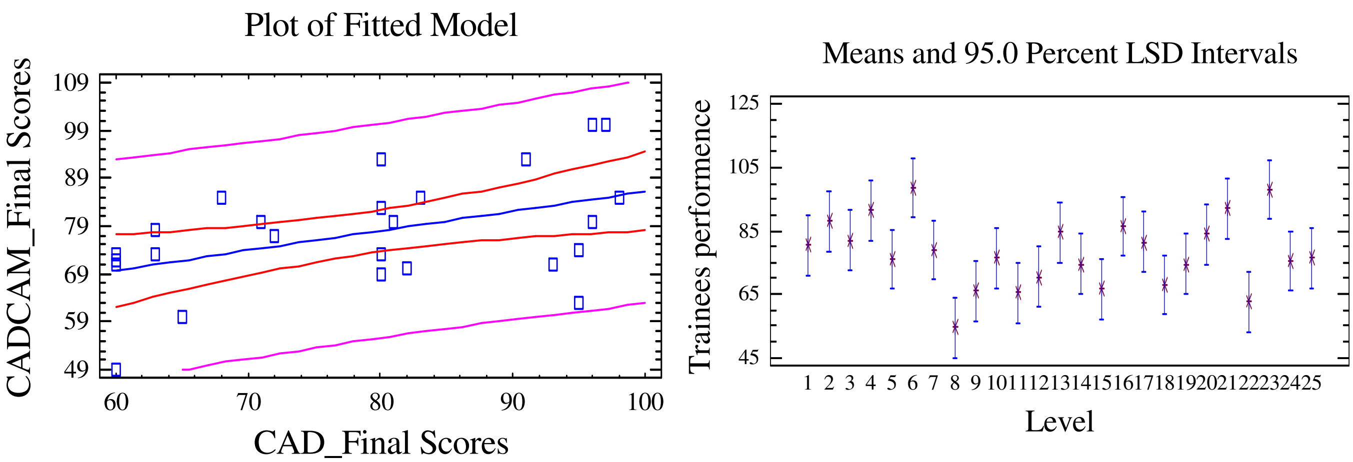

Figure 8. Regression model (CADCAM_Exam on CAD_Exam).

Table 12. Linear regression model of the *CADCAM_Final scores* on the *CAD_Final* scores.

Linear regression model				
CADCAM_Final Scores = 45.0749 + 0.411441*CAD_Final Scores				
		Standard	**T**	
Parameter	**Estimate**	**Error**	**Statistic**	**P-value**
Intercept	45.0749	12.5918	3.57971	0.0016
Slope	0.411441	0.157589	2.61084	0.0156

Analysis of variance

Source	**Sum of squares**	**Df**	**Mean square**	**F-Ratio**	**P-value**
Model	767.288	1	767.288	6.82	0.0156
Residual	2588.95	23	112.563		
Total (Corr.)	3356.24	24			

Correlation coefficient = 0.478137,
R-squared = 22.8615%,
Standard error of Est. = 10.6096.

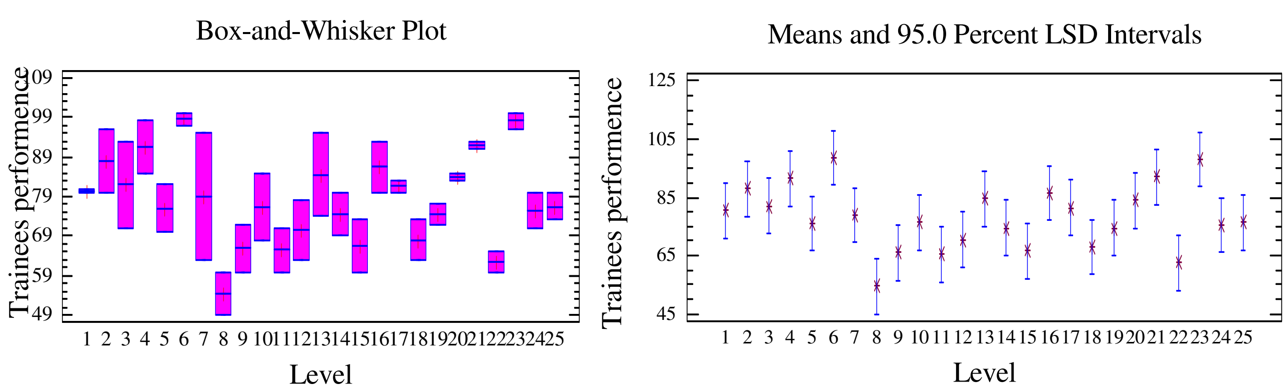

Figure 9. Box plot and 95% Tukey HSD intervals.

Table 13. Comparison of alternative regression models.

Model	Correlation	R-squared (%)
S-curve	-0.6399	40.95
Reciprocal-X	-0.6392	40.86
Double reciprocal	0.6321	39.96
Logarithmic-X	0.6310	39.81
Square root-X	0.6264	39.24
Linear	0.6217	38.65
Multiplicative	0.6216	38.64
Square root-Y	0.6134	37.63
Exponential	0.6032	36.38
Reciprocal-Y	-0.5760	33.18
Logistic	<no fit>	
Log probit	<no fit>	

Table 14. Analysis of variance for Trainee_Final_Score by factor.

Source	Sum of squares	Df	Mean square	F-ratio	P-value
Between groups	5809.28	24	242.053	2.88	0.0054
Within groups	2100.0	25	84.0		
Total (Corr.)	7909.28	49			

Table 15. Recap of distribution, mean and standard deviation of scores.

Interrelated courses	Cont. *Ass.* Scores/60			Exam scores/40			Final scores/100	
	Distribution	$\bar{X}$	S_X	Distribution	$\bar{X}$	S_X	$\bar{X}$	S_X
CAD course	Approximately normal	46.52	8.65	Non normal	32.24	8.04	80.93	13.13
CADCAM course	Approximately normal	47.04	7.24	Normal	30.84	6.17	76.23	13.31

Table 16. Recap of regression linear model.

Regression linear model	Correlation coefficient	R-squared (percent)	Predicted vs. observed scores
CAD_Exam on CAD_Cont.Ass.	0.355255	12.6206	Severe discrepancy
CADCAM_Exam on CADCAM_Cont.Ass.	0.621723	38.6539	Moderate discrepancy
CADCAM_Final on CAD_Final	0.478137	22.8615	Severe discrepancy

In addition, only one regression model proved linear. The two remaining are rather S-curved,

(v) The post-hoc Tukey test (HSD) reveals presence of individual differences among population of trainees graduating in 2006 through 2008. This means that differences between trainees are not due to random errors source, solely, but, at 95 % of C.I, due to others factors (method of training, built-in capability of trainers, shortage in resources, poor or inappropriate training programs, content, unfortunate selection of trainee/trainers at the outset, pedagogical approach, tools, software, heterogeneous candidates, etc.). Therefore, we recommend further investigations and complementary studies to enhance the training process as such and bring solutions to the numerous limitations which have come out in this study.

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