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The effect of the explicit teaching of qualitative structural analysis method on learning in structural design

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ABSTRACT: Structural engineers need to be able to effectively apply both the qualitative and quantitative structural analysis methods in solving civil engineering structural design problems. While civil engineering undergraduate programmes, in general, do provide training in the quantitative structural analysis methods, the qualitative methods have not received equal emphasis. The main objective of this study was to determine if the explicit teaching of qualitative structural analysis methods would enhance problem-solving skills in structural design. A quasi-experimental design method of pre-test and post-test with a control group was employed. The participants were two classes of civil engineering students, n_{expt}= 38 and n_{cont} = 40. The experimental group was exposed to the prescribed intervention, which was integrated into their normal design lectures, while the control group had their normal design lectures. The gain score means of the experimental and control groups were 23.45 and 13.22, respectively. A two-way ANOVA showed that there was a main effect of treatment that was irrespective of gender. This finding provides support for the benefits of the explicit teaching of qualitative structural analysis techniques in order to enhance problem solving skills in structural design.

INTRODUCTION

Accomplishments in structural design rely on an engineer's creativity, as well as structural analytical skills. Successfully solving a structural analysis problem is not solely dependent on an engineer's quantitative skills, as often reflected by the teaching emphasis in engineering education, but equally dependent on an engineer's qualitative reasoning skills [1]. Qualitative reasoning skills here generally refer to one's ability to reason with diagrammatic representations or, specifically, to an engineer's ability to visualise and sketch the deformations and nature of the forces in a structure.

Normally, in the early stage of structural analysis, a structural engineer will employ qualitative reasoning to infer the qualitative responses of a given structure. The qualitative responses of a structure are expressed by the qualitative deflected shapes, moments and reactions that are often presented in sketches and diagrams [2]. Therefore, the ability to reason with diagrammatic representations is a necessary initial step in structural design because the ability provides an intuitive understanding of the behaviour of the structure that helps an engineer to decide on the appropriate strategy for further analysis [2]. In other words, qualitative reasoning skills underlie qualitative methods and, therefore, provide a necessary foundation to the quantitative knowledge that engineers use in their understanding and construction of physical systems or structures. As such, a structural engineer needs to be able to effectively apply both qualitative and quantitative methods in order to solve civil engineering structural design problems successfully.

While civil engineering undergraduate programmes generally provide training in structural analytical methods, qualitative and quantitative methods have not received equal emphasis in engineering education. Strong emphasis is usually given to quantitative methods. There are a few educators who believe that it is necessary to explicitly teach qualitative methods [3]. However, most educators believe that the onus is on the student to acquire and develop somehow these skills.

When it does occur, the teaching of qualitative methods is often carried out implicitly and not explicitly, as in the teaching of quantitative methods. Little emphasis on qualitative methods can be seen in the extremely limited use of sketches and diagrams in problem solving. Rather, there is greater emphasis on quantitative methods – analytical and the mathematical techniques – at the expense of qualitative methods, which has resulted in less than adequate design skills among fresh engineering graduates [4][5]. The purpose of this study is to see if the explicit teaching of qualitative structural analysis methods (QSAM) to civil engineering students can make a difference in their abilities to solve structural design problems.

A similar study was carried out with polytechnic engineering students, indicating that graphical representations do help in improving students' conceptual understanding that lead to better problem solving in structural design [6]. The main difference between that study and the present one is in the research design and the attributes of the samples. The previous study uses a post-test only design method, while the present one uses a pre- and post-test method. The present sample can also be considered to possess higher academic abilities compared to the previous samples, as university intakes demand higher entry qualifications compared to polytechnic intakes. Furthermore, the polytechnic population has a higher male/female ratio of 70/30, while the university population has approximately equal male/female student ratio. The almost equal male/female student ratio is an advantage, as it permits the use of a slightly more advanced statistical technique to test treatment and gender interaction effect. Previously, one could only test for the equality of means between the two groups [6].

Research Questions and Hypotheses

The study is guided by three research questions and three null hypotheses. The research questions are as follows:

1. Does the explicit teaching of qualitative structural analysis techniques affect problem solving performance in structural design, irrespective of gender?
2. Is there a main effect of gender, irrespective of treatment?
3. Is there an interaction effect between gender and treatment?

The three null hypotheses are as follows:

1. There will not be a statistically significant difference in the gain-score means in structural design between the experimental and the control group irrespective of gender;
2. There will not be a statistically significant difference in the gain-score means in structural design between males and females irrespective of treatment;
3. There will not be a statistically significant interaction between gender and treatment.

Methodology

The population is made up of third year civil engineering students in at Tun Hussein Onn University College of Technology in Johor, Malaysia. The samples were two intact classes of civil engineering students. The control and the experimental group consisted of two intact classes of students: $n_{cont} = 40$ and $n_{expt} = 38$ students, respectively.

Using intact classes of students means that the subjects were maintained in their natural setting and learning environment, which ensured ecological validity. Ensuring ecological validity would have been impossible had the experimental design with random sampling method been used. Although random selection and assignment have not been used, the two groups are not expected to be vastly different with respect to the relevant attributes, namely: gender proportion, age, academic abilities, attitudes towards sketching and drawing, and spatial visualisation abilities. Evidence of the groups' equivalence is provided in the results section.

Research Design and Procedures

A quasi-experimental design method of pre-test and post-test with a control group was employed for the study. The design is said to be quasi-experimental because two intact classes of students were chosen, as opposed to the random selection and assignment of subjects. This design is preferred over the true experimental method due to the benefits gained as stated earlier.

The study was carried out over a semester period. Topics taught over the semester were broadly divided into two, namely steel design and reinforced concrete design, which were taught either in Session I or Session II of the semester. Session I refers to the first half of the semester, while Session II refers to the second half of the same semester. For practical reasons, the control and the experimental group had their reinforced concrete design and steel design lectures, respectively, during Session I. The reverse was true for Session II. For each group, the data was gathered during the reinforced concrete design session. The same lecturer taught both groups on reinforced concrete design to eliminate teacher differences from confounding the results.

The control group was given a pre-test on structural design problem solving in the first week of Session I, followed by the normal lectures and a post-test at the end of the same session. Similarly, in Session II, the experimental group was given the same pre-test followed by intervention and a post-test at the end of the session. The gain scores were compared in order to determine the mean difference in learning gains for both groups.

To provide evidence for groups' equivalence (as mentioned under the population and sample section), questionnaires and a spatial ability test instrument were prescribed at the beginning of the study in order to gather information on the following variables that are found to affect learning in general, namely: age, gender, academic ability, attitude towards sketching and drawing, and spatial visualisation ability.

Research Instruments

Three data collection instruments were employed in the study; a Structural Design Instrument (SDI), an Attitude Questionnaire and a Spatial Visualisation Ability Test Instrument (SVATI). The Structural Design Instrument (SDI) is an achievement test instrument used to measure problem-solving skills in structural design. It has been designed and successfully used in a previous study [6]. The SDI is made up of 22 items that represent the cognitive categories of Bloom's taxonomy [7]. The items were classified into three categories, namely:

- The knowledge of concepts category;
- The applications category;
- The analysis and evaluation category.

Collectively, these items measure problem-solving skills in structural design. The SDI has an estimated Cronbach alpha reliability coefficient of 0.72 based on the actual study and is deemed to be sufficiently reliable for the purpose of this study. The current reliability is similar to a previous study, which had a value of 0.74 [6].

The second instrument, the Attitude Questionnaire, is a 28-item instrument that measures students' attitudes towards sketching and drawing. The instrument has three sub-scales. The questionnaire has been adapted from an instrument previously used in another study [8]. It has a reliability of 0.81 in the present study, which can be considered to be adequately reliable.

The third instrument, the SVATI, has been successfully used in a previous study [9]. The reliability in this study is 0.74 based on the combined scores of the control and the experimental group. The reliability is also of an acceptable level and similar to a previous study [9].

Intervention Materials and Procedures

The teaching of qualitative structural analysis method (QSAM) was integrated into the normal structural design lectures to maximise learning transfer. Early in the intervention, the importance of qualitative reasoning to structural analysis and design was explained followed by demonstrations on how QSAM is applied.

Elements of QSAM were introduced to students incrementally over a five-week period. Application examples include beams and frame analysis. During the intervention, extensive use was made of graphical representations, such as freehand sketching and standardised drawings, emphasising the role of qualitative reasoning in structural analysis and design. However, due to time constraints, a teacher-centred approach, whereby the lecturer plays the dominant role, was used, although a student-centred approach would be more likely to produce the desired results. The materials for the teaching of the methods were adapted from Brohn [1][10].

DATA ANALYSIS RESULTS AND DISCUSSION

Table 1 shows the statistics of the relevant variables for groups' equivalence, ie gender proportion, mean age, mean Cumulative Point Average (CPA), mean score on attitude towards sketching and drawing, and mean score on spatial visualisation ability (SVA) for the experimental and control groups. Although the groups' statistics are not exactly matched, they are nevertheless very close. In fact, independent *t*-tests (for unequal variance) carried out on each of the differences revealed no statistical significance at the 5% level, indicating that the differences are most probably due to chance. Therefore, it can be concluded that the baseline attributes of the two groups are similar with respect to the relevant variables and, therefore, can be considered to be equivalent for the purposes of the study.

Table 1: Gender, mean age (year), CPA, attitude to sketching and drawing, and SVA for the experimental and control groups.

	Gender	Age	CPA	Attitude	SVA
Exp. Group	F = 18 M = 20	22.1	2.78	$\bar{x}$ = 98	$\bar{x}$ =14.5
Control Group	F = 18 M = 22	22.2	2.76	$\bar{x}$ = 99	$\bar{x}$ =15.8

Research Procedures

In order to determine the effect of the intervention on problem solving performance, a comparison was made between the gain scores on the SDI for the two groups. To provide evidence for a *non-study-specific effect*, data for the groups' performance in the end-of-semester examination was also gathered and compared. While the emphasis of the SDI is more on qualitative reasoning, as a precursor to quantitative reasoning, the emphasis of the end-of-semester examination was more on the mathematical and analytical reasoning aspects of structural design. The examination paper consisted of four-item essay-type questions, with two items on steel and reinforced concrete design, respectively. In this study, only the scores on the reinforced concrete design items are considered. Information from the two sources can provide evidence of a more encompassing learning outcome, ie qualitative and quantitative learning outcomes.

Table 2 shows the mean gain scores on the SDI and the mean scores in the end of semester examination for the two groups. Overall, the experimental group had higher mean scores compared to the control group on both the SDI and the end-of-semester examination paper.

To determine if the difference in mean scores was statistically significant on the SDI, the mean gain scores on the SDI for both groups were compared using a parametric test, a two-way analysis of variance (a two-way ANOVA), with teaching intervention and gender as the independent variables, and the mean gain scores as the dependent variable. A parametric test was chosen upon ensuring that the data was normally distributed.

Table 2: Mean scores on the SDI and the end-of-semester examination paper.

		SDI (Gain score)	End-of-Semester Examination (Reinforced concrete)
Expt. Group	$\bar{x}$ =	23.45	75.79
	s =	15.04	16.31
Control Group	$\bar{x}$ =	13.22	66.92
	s =	10.48	18.83

The two-way ANOVA results in Table 3 show that there is a main effect in the treatment, irrespective of gender, where the difference in the mean scores of the two groups are statistically significant at the 5% level of significant (p=0.026). In other words, the mean score of the experimental group is statistically significantly higher than the mean score of the control group. However, there is no statistically significant interaction effect between gender and treatment, and there is no statistically significant main effect on gender irrespective of treatment.

Table 3: Results of the two-way ANOVA on the SDI scores using *SPSS* version 11.

Source	*SS*	*df*	*MS*	*F*	*p*-value
Gender	329.82	1	329.82	96.46	0.065
Group	2037.38	1	2037.384	595.89	0.026**
Gender Group	3.419	1	3.419	0.02	0.889
Total	12955.18	74	175.07		

** $p < 0.05$, statistically significant

Comparing the mean gain in learning for the two groups, the experimental group is 12.97 points higher than the control group. This means that the effect size for the gain in learning for the experimental group is estimated to be 0.86, based on the experimental group's standard deviation [11]. This means that about 85% of the control group was below the average person of the experimental group, which is, indeed, academically significant.

In order to investigate the prescribed intervention effect on examination performance, the differences in groups' means for the examination scores were tested using a parametric test for assessing means difference – the independent equal variance two-tailed *t*-test. This particular parametric test is appropriate as the groups are independent, the distributions have been found to be normal, and the variances are equal, as indicated by the non-significant *F*-test result shown in Table 4.

The *t*-test result given in Table 4 indicates that the experimental group is statistically significantly different from the control group at the 5% level of significant (p<0.05). Since the experimental group has a higher mean score, this means that the experimental group is better than the control group. In other words, students who were explicitly taught QSAM learnt more compared to those that who were not.

Table 4. Results of the independent samples *t*-test using *SPSS* version 11 for the differences between the means of the examination scores for the control and the experimental groups.

Levene's Test for Equality of Variances		*t*-test for Equality of Means			
F	*p-value.*	*t*	*df*	*p-value*	Mean Difference
1.15	0.29	2.18	76	0.03*	8.87

*p< 0.05, statistically significant.

Again, it was found that that the effect size was about 0.54, based on the standard deviation of the experimental group. This means that about 54% of the control group was below the average of the experimental group. These findings clearly support the hypothesis that the explicit teaching of QSAM produces a positive effect on problem solving performance in structural design, ie the desired effect. The effect of QSAM is significant on both, ie performance in qualitative problem solving (indicated by scores on the SDI) and quantitative problem solving (indicated by scores on the end-of-semester examination).

The significance of the results is further underscored by the large effect size for the gain in learning, which means that not only are the results statistically significant but, more importantly, the results are academically significant. Taking into account the teacher-centred approach that was used in the intervention instead of a student-centred one, which is thought to be more effective, the finding is also of practical significance as the teacher-centred approach is indeed the most widely practiced in engineering education.

The present results indicate that the positive effect of the explicit teaching of QSAM is not limited to students of lesser academic ability, but equally applicable to a group of students with higher abilities. Therefore, the results can be interpreted in the following manner, ie irrespective of academic ability, students do benefit from the explicit teaching of QSAM. With regard to the interaction effect between gender and treatment, the results show that there is no statistical significance at the 5% level of significance. This means that the explicit teaching of qualitative structural analysis techniques equally benefits all students – irrespective of gender.

CONCLUSION

This study set out to determine if the explicit teaching of QSAM has an impact on problem solving in structural design. The findings indicate that the explicit teaching of QSAM does indeed make a difference to students' performance. Not only do students perform better on the study-specific test, students also performed better in their end of semester examination, which is designed to measure a more quantitatively biased learning outcome of the subject. This indicates that explicitly teaching QSAM not only promotes a close learning transfer, but also promotes equally a more general learning transfer within a subject area, which is the goal of education.

The results of the study are not only statistically significant but are also academically and pedagogically significant. The academic significance is clearly apparent in the gain in learning of the treatment group, which is much larger than the control group. The fact that the intervention was teacher-centred rather than student-centred shows that a teacher-centred approach does not necessarily generate ineffective instruction (if it is well designed), which makes the finding pedagogically significant. Nevertheless, it is still expected that a student-centred approach would elicit a larger magnitude of learning gain compared to a teacher-centred approach, a hypothesis that may be the focus for future study.

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